RESPONSES OF TENSION LEG PLATROM (TLP) DUE TO WAVE SPECTRUM

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JANUARY 2009

CERTIFICATION OF APPROVAL

RESPONSES OF TENSION LEG PLATFORM (TLP) DUE TO WAVE SPECTRUM

by

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(CIVIL ENGINEERING)

Approved:

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ariff Bin Mohd Abdul Wahid

EXECUTIVE SUMMARY

This dissertation report is to provide an insight into the accomplishment of the Final Year Project (FYP) for the Civil Engineering Department of University Technology PETRONAS (UTP). The objective of this report is to record all the relevant activities and studies that contribute towards the author's cognitive and practical skills during the Final Year Project (FYP); Responses of Tension Leg Platform Due to Wave Spectrum. It contains the summary of overall project studies, which includes all the relevant activities that have contributed towards the success of its completion. It should be noted that this Final Year Project (FYP) is a methodology of learning and practicing Civil/Structural engineering in Oil and Gas Industry.

This report covers mostly the studies as well as laboratory experiments undertaken through the two semesters of the program. This is to show how far this program has contributed towards the achievement of the Final Year Project objectives in helping UTP to produce well-rounded graduates.

The Lesson Learned and Experiences Gained throughout this project will cover all knowledge especially about deep water industry practices that were obtained throughout the project period. The Final Year Project (FYP) assessment shall evaluate all relevant learning mechanisms; both that can be practiced and that only can be directly observed. This document addresses all the studies and result found on Civil/Structural Engineering.

ACKNOWLEDGEMENT

This Final Year Project (FYP) involves many parties in order to achieve a great educational session for a Civil Engineering student. It is a good opportunity to learn and practice engineering in an industry especially in Offshore Structure and Oceanography. Hence, deepest gratitude goes to AP. Dr. Kurian V. John, Lecturer of Civil Engineering Department of Universiti Teknologi PETRONAS, for the project title offered in Final Year Project. Without his guidance and patience, the author would not be succeeded to complete the project. The gratitude also goes to the Final Year Project Coordinator, Mr. Kalaikumar a/l Vallyutham and Mrs. Nabila Abu Bakar for providing the author with all initial information required to begin the project.

The author wishes to take this opportunity to express his utmost gratitude to the Mr. Zhafran Sulaiman, Mr. Mohd Redzuan Abdan and Mr. Melvin Lau Ik Yeong for their time and effort to assist the author in completing the project. Without the cooperation of these individuals, no doubt the author would have faced some minor complications through out the course.

To all the technicians in Civil Engineering, Chemical Engineering and Mechanical Engineering Departments, thank you for assisting the author in completing his project.

To all individuals that has helped the author in any way, but whose name is not mentioned here, the author thanks all of you.

Abstract

Tension leg platform (TLP) is among the compliant platforms that vertical moored with excess buoyancy. The design of TLP is as the same design of other moored structures in horizontal plane. First order wave force is presented as the dynamics response of TLP and considered the degrees-of-freedom surge, sway, heave, roll, pitch and yaw. Included in this report are the history and the fundamental design of the tension leg platform. Besides that, the basic concepts of the buoyancy force and wave spectrum are also included in this TLP. The calculation of horizontal force and vertical using the Morison equation and RAO (Response Amplitude Operator) are included in chapter 3. The scale model dimension and drawing of Ram Powell is provided in this report. The effects of different parameters that influence the response of the TLP are then investigated. There are graphs in the result consisting of the P-M and JONSWAP spectrum graph, wave elevation graph, time series of horizontal forces graph, RAO (Response Amplitude Operator) versus frequency graph, surge, heave, pitch spectrum graph and surge, heave and pitch response graph. All this graphs are the result from calculation using the Ram Powell Tension Leg Platform criteria and specification. Based on the analysis of the real platform, it gives idea on the response of tension leg platform model prototype due to the wave spectrum. Attached in this report is the work schedule for the task needed for the way forward. Included in this report is the model testing of fabrication model at Offshore Laboratories. From the model testing, graph of fabrication model responses due to wave is plotted.

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CHAPTER 1.0
INTRODUCTION

1.1 Background of Study

Due to urbanization, the need of oil and other petroleum products has been rapidly increasing over the year. This has led to the scarcity of easily retrieved oil. As a result, petroleum companies are motivated to go to deeper ocean to extract oil and other resources. Tension Leg Platform (TLP) is a deep water platform that is preferable for deep water drilling. TLP is a compliant structure consisting of a pontoon, columns and a deck and vertically moored at each corner by tendons. Each tendon at the TLP is designed to be pre-tensioned so it does not go slack due to variations in the extreme sea conditions. In recent years, Gulf of Mexico is the place where a large number of TLPs was built. The tension in the tendons is the function of the environment conditions under which the structure must operate. Most of TLPs are available for use in water depths of up to 6000 ft. A schematic diagram of a typical TLP is shown in Fig. 1.11.

The deepest TLP in the world is designed to process 120,000 barrels of oil and located at 1311 m (4300ft) water depth. The cost of this platform was approximately $210 million. Due to the million investments, the interest in responses of structure caused by the wave spectrum leads to improved performance and increased design lives. The response of TLP structure is a very complex phenomenon and governs from equation of motion that nonlinear and depends on both time and space. Bokaian [2,3] studied the effect of a constant axial force on natural frequencies and mode shapes of a uniform single-span beam. Luo [4] investigated the Eigen properties of the lateral vibration of an axially loaded infinite beam subjected to a harmonically varying concentrated transverse force at the center. Jain [5] analyzed the dynamic response of a TLP to deterministic first-order wave forces.

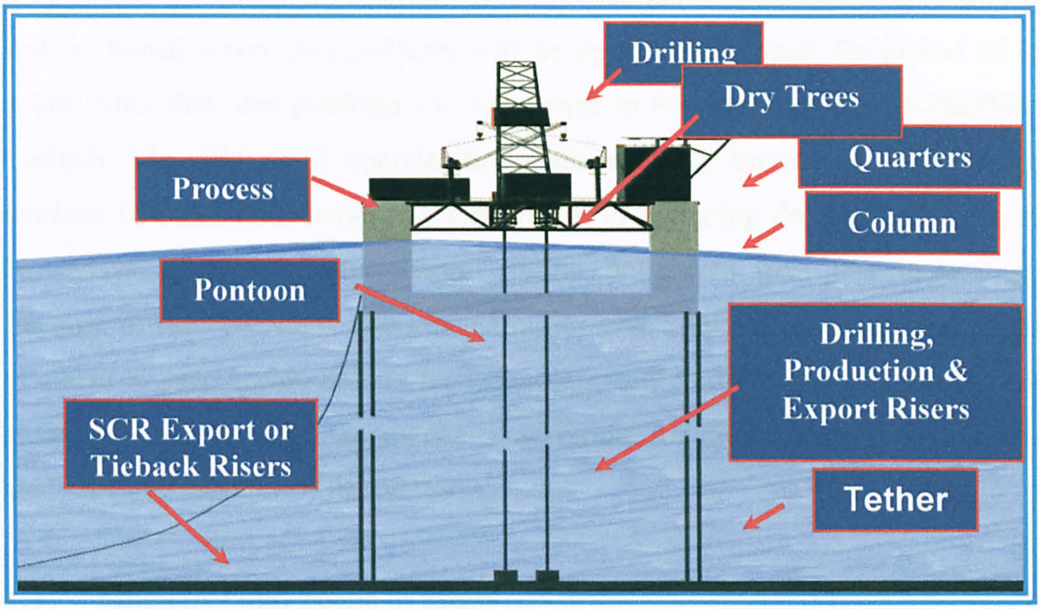


Figure 1.11: Schematic diagram of tension leg platform.

This study also involves the response of platform due to varying were performed for different values tension in the cable produced by hydrodynamic drag force. The study of parameter of pretension and natural period for surge, sway and yaw that do not cause resonance as it was well above the natural frequency of external loads. The heave frequency of oscillations of TLP is leading to large tension in tether and resonance. From the analysis of the heave motion, it was observed that the fluctuation of tether tension was of much concern from the fatigue point of view. Thus, analysis was done when neglecting the various degrees of freedom.

1.2 Problem Statement

Recently, oil and gas companies look forward for deep water exploration in order to explore the potential oil region due to the rapid increase of oil price in the world markets. The exploration of petroleum in deepwater faces huge challenge of environmental loads acting on the platform. There is need for analysis of responses of deep water platform when undergo environmental loads like wave loads for estimation of design life period. The big oil and gas companies like

Murphy oil Corp. and Shell take initiative for deep water exploration because of oil fields at shallow water area are getting exhausted. Recent development of deep water platform in Malaysia is Semi submersible platform at Gumusut Kakap, Sabah where this platform will be operating by Shell for period of 15 years. After that, this platform will hand over to PETRONAS and PETRONAS Carigali Sdn. Bhd. will operate the platform. With limited of PETRONAS workers that has knowledge and technology in operating deep water platform. Nowadays, consultant will charge million dollars to give this technology. Because of this, the study was carried out to give knowledge on the deep water platform to save billion dollars for technology and knowledge resources. In this study, they are required to test the scale model for the extreme condition and analyze the behaviour of the platform.

1.3 Objective and Scope of Study

The objectives of this study are:

1. To prepare a detailed literature survey report about the tension leg platform existing and under design/construction stage.
2. To analyze the tether forces of the platform subjected to random waves.
3. To determine the effect of different spectra on the responses.
4. To test a model in the wave tank or flume and determine the responses for comparison with analytical result.

The scope of this study is to investigate and predict the responses of the Tension Leg Platform (TLP) due to the wave spectrum and to compare the results with the actual platform performances. In order to achieve this, a few tasks and researches need to be carried out by collecting all technical details regarding the existing tension leg platforms. All research materials are limited at the Information Resources Center Universiti Teknologi PETRONAS, IRCUTP. This research also focused on the fundamental behavioural aspects of the platforms. This study only limited to the two spectrums, P-M spectrum and JONSWAP spectrum. The dynamic analysis and frequency domain will be carried out.

CHAPTER 2.0
LITERATURE REVIEW AND THEORY

2.1 History

Ram Powell TLP

Ram Powell platform was designed and engineered by a joint partner team made up of personnel from Shell, Amoco and Exxon. It was supported from outside contractors in Louisiana and Texas. The design of that platform can withstand the hurricane-force waves. The hull was constructed in October 1996 and demobilized to Aker Gulf Marine's Ingleside yard in Texas in November 1996. The hull is comprised of four circular steel columns, 66.6 ft in diameter and 165 ft-high. They are connected by a ring pontoon structure, 27 ft wide and 24.5 ft high, with a rectangular cross section. The hull weight is approximately 15, 000 t. The first module of the deck was loaded out on 6^{th} November 1996 with shipment of the remaining modules concluded by the end of December 1996.

The deck of Ram Powell is open truss/deep girder type. Its measure is 245ft X 245 ft and stand 40 ft high. The weight of deck is approximately 8,100t and comprised of five modules, namely: wellbay, quarters, process, power and drilling. It can accommodate 100 people along with the control room and an emergency- response centre. 12 tendons are installed in this TLP and each of the columns has 3 tendons. Diameter of the tendon is 28 in and wall thickness is 1.2in. Each tendon is approximately 3,145 ft long and the total weight for the 12 tendons is approximately 10,000t. These tendons are attached to the foundation system and held in place by 12 piles. The piles are 84ft diameter and 349 ft long. See figure 2.11 for the overall picture of the platform.

Figure 2.11: Picture of Ram Powell tension leg platform

Hutton TLP

The first tension leg platform that was operated in the North Sea in 1984 is Hutton TLP. Hutton TLP has six-columns and all connected at their base by the rectangular pontoons. The desk is a structural component that comprises of deep plate girders. The deck and the hull were fabricated separately and towed to a deepwater site where it will join together. The overall view of the platform is shown in figure 1.12. This platform was positioned over the foundation templates and restrained from the lateral excursions of onward ballast. Refer table 2.1 for comparison of TLPs.

Figure 2.12: Picture of Hutton tension leg platform

Snorre Platform

The Snorre Tension Leg Platform (TLP) has been operating successfully in the North Sea, offshore Norway, since 1992. It's located about 30 km north east of the Stratfjord field and 150 km west of Flore on Norway's west coast. This platform moored to the seabed by a system of tethers, at a water depth of approximately 310 m. The topsides are supported by four cylindrical columns, interconnected by means of pontoons. A system of production risers is capable of producing up to 60,000 barrels a day from the underlying Snorre field (figure 1.13).

Figure 2.13: Picture of Snorre tension leg platform

Table 2.1: Design Data and Main Characteristic of TLPs.

Data	Ram Powell TLP	Hutton TLP	Snorre TLP
Water depth (m)	1048	148	310
Column spacing (m)	-	-	76
Displacement (kN)	49,100	616500	1065000
Payload (kN)	-	180000	250000
Deck dimension (m)	75 X 75	96 X 92	130 X 92
Total pretension (kN)	-	130000	250000
Height of TLP (m)	14	69	63
Corner column Diameter (m)	21m	17.7	25

Centre column diameter (m)	-	14.5	-
Pontoon dimensions (m)	7.4 X 8.2	8 X 10.8	11.5 X 11.5
Sea spectrum Hs (m)	-	16.6	15
Tz (sec)	-	13.9	-
Current velocity (m/sec)	-	0.85	1
Wind speed (m/sec)	-	44	41
No. of tethers	12	16	-

2.2 Tension Leg Platform

A Tension Leg Platform (TLP) is a buoyant platform that is widely used in deep water area. The TLP is a platform that is similar to the fixed platform except it is maintained on location through the use of tethers held in tension by the buoyancy of the hull. Attached to the platform is a set of tension legs or tendons that uses the tether system. These tethers will be connected to the template or foundation on the seafloor. The template is held in place by piles driven into the seafloor. The platform can undergo for horizontal movement but this method dampens the vertical motions of the platform. All facilities for daily operation in tension leg platform like topside facilities (processing facilities, pipelines, and surface tress) are same as conventional platform.

Rest on the seabed is foundation for the link between the seafloor and the TLP. Foundations are the templates laid on the seafloor that secured by concrete or steel piles driven into the seafloor. Other design can be used for foundation like gravity foundation. All foundations are built onshore in fabrication yard and towed to the site. Sometimes, 16 concrete piles with dimensions of 100 ft in diameter and 400 ft long are needed (one for each tendon).

One of the buoyant structures that support the deck section and production equipment of the platform is called Hull. The conventional hull has four air-filled columns supported by pontoons, similar to a semisubmersible drilling vessel. Rested on the hull is the deck foot the surface facilities. Taut moorings or "tension legs" are required to secure the structure to the seafloor. The range of the column in the hull up to 100 ft in diameter and up to 360 ft in height but the hull measurement always depend on the size of the column and platform itself.

Modules are units that make up the surface facilities on the deck section of the platform. Back to the early TLP development, the surface facilities need to fabricate in separate (modules) due to cost effective. The parts that include in modules are wellbay, power, process, quarters and drilling. A common surface facility for TLP is 65,000 sq ft. The typical platform can accommodate 100 people, depending on the type and scope of activity being performed. Drilling rig located on a larger TLP would have a 1.5 million-pound pull derrick, a 2,00-hp-top-drive derrick, and three 2,200-hp pumps.

The first common equipment installed at the site is templates. Templates provide a frame on the seafloor in which to insert either conductors or piles. There are a number of types of templates that may be used in a TLP to support drilling, foundation integrity, or the integration of the two. The function of drilling template is to guide locating and drilling well. One single piece or separated pieced for each corner of the TLP platform are foundations templates. The foundation piles are driven through the foundation template. Integrated template is a single piece that contains all drilling support, anchors the tendons and locates and guides the foundation piles. The drilling template can be installed and drilling can begin while the foundation template is being designed and built.

2.3 Advantages of TLP

The concept of TLP that floating in water provides several advantages in structural concept in deep water. One of the advantages includes maintainability of well and riser because of minimal movement in the vertical direction. The interesting of the fabrication and hook up of the platform is the construction of this platform can be made onshore. The mechanism of floating structure of TLP platform offer better reduction in cost like fixed platform, the cost will increase when the water depth increase. For the TLP, the increase in cost due to water depth only effect by the mooring system and its installation.

CHAPTER 3.0

METHODOLOGY

3.1 Literature Survey.

Investigations of the tension leg platform as the deepwater platform were done by studying all the journals and related book. All materials were searched through the internet and from the libraries to get available information on the usage of tension leg platform in offshore context. The details regarding to the performance of the several of tension leg platform with regard to the dynamic response was collected. The simple analysis of surge, heave and pitch motion due to the wave spectrum were carried out. Figure below is shown for the schematic methodology for this study. The response of scale model TLP was compared with the actual platform data. Paulling and Horton (1970) explained a method of predicting the platform motion and tether forces due to regular or random wave using linearized hydrodynamics synthesis technique.

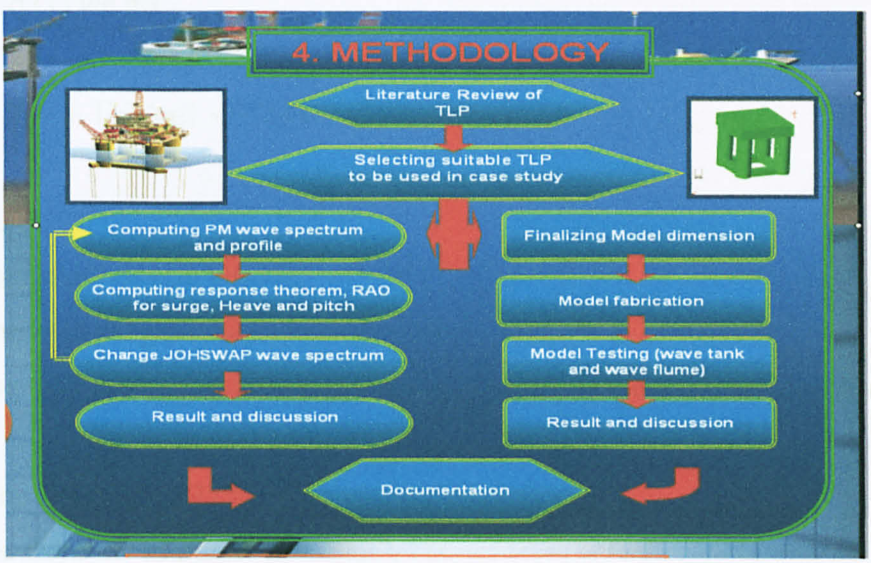


Figure 3.11: Schematic methodology diagram

The equation of motion describing the dynamic equilibrium between the inertia, damping, restoring and exciting forces can be assembled as follows:

[M]{X'} + [C]{X''} + [K]{X} - {F({X},{X'},{X},t)}

where,

[M] is the diagonal mass matrix for all the six degrees-of-freedom;

[CI is the damping matrix;

[K] is the nonlinear stiffness matrix;

{F} is the vector of forcing function;

{X}, {X} and {X'} are the displacement, velocity and acceleration vectors, respectively.

In this study, the scale model needs to find the buoyancy force in order for the scale model floating. Based on that, from the equilibrium position (Fig 2), summation of forces in the vertical direction gives;

$W + T = F_b$ (1)

Where

$F_b = p$ (pi) (g) $(D^2{}_cD_r + D^2s)$ (2)

From Eq (1) we get

D r = [{(W + T)/p/gg} - D2s]/D~ (3)

Where,

Fb is the total buoyancy force,

W is the total weight of the platform in air,

T is the total instantaneous tension in the tethers, p is the mass density of sea water,

Dc is the diameter of TLP columns,

D is the diameter of pontoon,

s is the length of the pontoon between the inner edges of the columns and *Dr* is the draft.

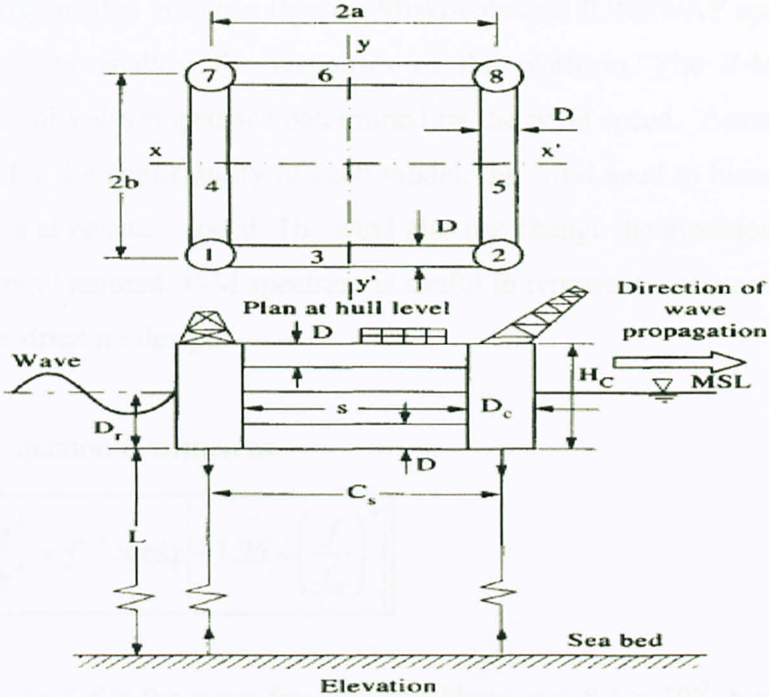


Figure 3.11: Plan and elevation of the proposed TLP model

3.2 Wave spectrum

Pierson Moskowitz Spectrum Calculation

In This study involves analysis of response of the platform due to wave spectrum. Wave spectrum is generally based on one or more parameters e.g., significant wave height, wave period and shape factor (Chakrabarti, S.K. (1994). The common single-parameter spectrum is the Pierson-Moskowitz (1964). This model uses significant wave height or wind speed as the parameters. The significant wave height Hs at the Gulf of Mexico is 11.6m reference from American Petroleum Institute (APA). The peak frequency is calculated by using the formula below and need to use Hs given in APA.

$$\boxed{W_o{}^2 = \frac{0.161g}{Hs}} \tag{3.21}$$

$$\boxed{F_0 = \frac{W_0}{2\pi}} \tag{3.22}$$

The objective of this is to use Pierson-Miskowitz and JONSWAP spectrum as a wave model to analyze the responses of the platform. The P-M spectrum describes a fully-developed sea determined by the wind speed. Assumption was made that for the applicability of such model, the wind need to blow all area at the platform at constant speed. The wind also not change the direction more than specifies small amount. P-M spectrum is useful in represent a severe storm wave in offshore structure design.

The basic equation is written as

$$\boxed{S(f) = \frac{\alpha g^2}{2\pi^4} \times f^{-5} \times \exp\left| -1.25 \times \left(\frac{f}{f_0} \right)^4 \right|} \tag{3.23}$$

where $\omega = 2\pi$ f, f is the wave frequency in Hertz, a = 8.1×10^{-3}, b = 0.74, $\omega_0 = g/U_{19.5}$ and $U_{19.5}$ is the wind speed at a height of 19.5 m above the sea surface, the height of the anemometers on the weather ships used by Pierson and Moskowitz (1964). Then frequency from 0.005 to 0.295 will be calculated to get the each S (f) for the each frequency. Then, the graph Frequency Vs S (f) will be plotted.

The significant wave-height is calculated from the integral of S (ω) to obtain:

Wave height

$$\boxed{H(fi) = 2 \times \sqrt{2 \times \Delta f \times s(fi)}} \tag{3.24}$$

Significant height

$$\boxed{M = \Delta f \times sum\,of\;S(f)} \tag{3.25a}$$

$$\boxed{Hs = 4\sqrt{M_o}} \tag{3.25b}$$

JONSWAP Spectrum

Hesselmann et al., (1973) found that the wave spectrum is never fully developed based on his analyzing data collected during the Joint North Sea Wave Bservation Project JONSWAP. They proposed that a spectrum ~~is~~ continues to develop through non-linear, wave-wave interactions even for very long times and distances. They therefore proposed a spectrum in the form (Figure 3.26):

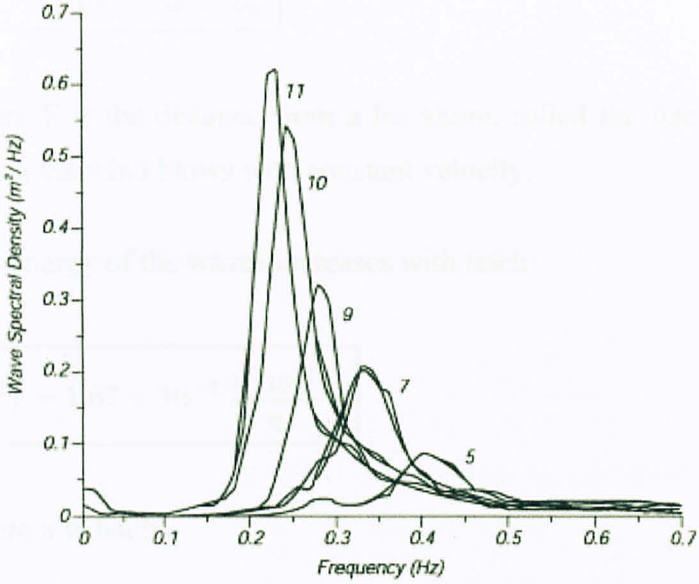


Figure 3.26 Wave spectra of a developing sea for different fetches according to Hasselmann et al., (1973).

The equations of JONSWAP are listed below;

$$\boxed{S(\omega) = \frac{\alpha g^2}{\omega^5} \exp\left[-\frac{5}{4}\left(\frac{\omega_p}{\omega}\right)^4\right] \gamma^r} \tag{3.26a}$$

$$\boxed{r = \exp\left[-\frac{(\omega - \omega_p)^2}{2\,\sigma^2\,\omega_p^2}\right]} \tag{3.26b}$$

Wave data collected during the JONSWAP experiment are used to determine the values for the constants in (3.26):

$$\boxed{\alpha = 0.076\left(\frac{U_{10}^2}{F\,g}\right)^{0.22}} \tag{3.27a}$$

$$\boxed{\omega_p = 22\left(\frac{g^2}{U_{10}F}\right)^{1/3}} \tag{3.27b}$$

$$\boxed{\gamma = 3.3} \tag{3.27c}$$

$$\boxed{\sigma = \begin{cases} 0.07 & \omega \leq \omega_p \\ 0.09 & \omega > \omega_p \end{cases}} \tag{3.27d}$$

where F is the distance from a lee shore, called the fetch, or the distance over which the wind blows with constant velocity.

The energy of the waves increases with fetch:

$$\boxed{\langle \zeta^2 \rangle = 1.67 \times 10^{-7} \frac{(U_{10})^2}{g} x} \tag{3.28}$$

where x is fetch.

The JONSWAP spectrum is similar to the Pierson-Moskowitz spectrum except that the waves continues to grow with distance (or time) as specified by the α term, and the peak in the spectrum is more pronounced, as specified by the γ term. The latter turns out to be particularly important because it leads to enhanced non-linear interactions and a spectrum that change in time according to the theory of Hasselmann (1966).

3.3 Calculation method for Horizontal forces.

The calculation of force using the Morison equation to find the total force due to the inertia and drag forces linearly added together. This horizontal forces will be used to calculate the surge motion and it is shown below, the steps to find the horizontal force by using the Morison equation.

Step 1: Calculation of Wave Airy Theory

This Ram Powell platform is a deepwater platform, so wavelength can be determined by using equations below

$$\boxed{L = \frac{gT^2}{2\pi}} \tag{3.31}$$

Or

$$\boxed{L = \frac{gT^2}{2\pi}\sqrt{\tanh\frac{4d\pi^2}{gT^2}}} \tag{3.32}$$

Step 2: Calculation of wave number will be calculated as below

$$\boxed{K = \frac{2\pi}{L}} \tag{3.33}$$

Step 3: Calculation of Angular wave frequency expression as shown below

$$\boxed{\omega = \frac{2\pi}{T}} \tag{3.34}$$

$$\boxed{\theta = kx - \omega t - \varepsilon n} \tag{3.35}$$

Step 4: Calculation of Water Particle Velocity

$$\boxed{u = \frac{\pi H}{T} \times \frac{\cosh ks}{\sinh kd} \times \cos\theta} \tag{3.36}$$

Step 5: Calculation of water Particle Acceleration

$$\boxed{u' = \frac{2H\pi^2}{T^2} \times \frac{\cosh ks}{\sinh kd} \times \sin\theta} \tag{3.37}$$

Step 6: Calculation of Drag Force

$$\boxed{Fd = \rho \times Cd \times \frac{D}{2} \times |u| \times u.ds} \tag{3.38}$$

Step 7: Calculation of Inertia Force

$$\boxed{Fi = \rho \times Cm \times \frac{\pi}{4} \times D^2 \times u'.ds} \tag{3.39a}$$

Step 8: Calculation of Total Force

$$Total\ Force,\ F = Fd + Fi \tag{3.39b}$$

3.4 Calculation method for Vertical wave forces.

The calculation of force using the Morison equation to find the total force due to the inertia and drag forces linearly added together. This vertical force will be used to calculate the heave motion and the steps to find the vertical force by using the Morison equation is shown below:

Step 1: Calculation of Wave Airy Theory

This Ram Powell platform is a deepwater platform, so wavelength can be determined by using equations below

$$\boxed{L = \frac{gT^2}{2\pi}} \tag{3.41}$$

Or

$$\boxed{L = \frac{gT^2}{2\pi}\sqrt{\tanh\frac{4d\pi^2}{gT^2}}} \tag{3.42}$$

Step 2: Calculation of wave number will be calculated as below

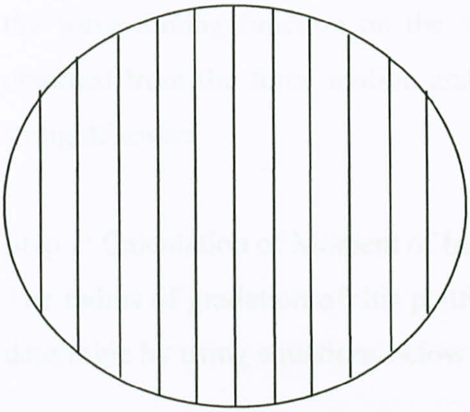
$$\boxed{K = \frac{2\pi}{L}} \tag{3.43}$$

Step 3: Calculation of Angular wave frequency expression as shown below

$$\boxed{\omega = \frac{2\pi}{T}} \tag{3.44}$$

$$\boxed{\theta = kx - \omega t - \varepsilon n} \tag{3.45}$$

Step 4: Calculation of plan area



For this part, AUTOCAD software was used to find the area for each strip.

Step 5: Calculation of Dynamics Pressure

$$\boxed{P = \rho g \frac{H}{2} \frac{\cosh ks}{\cosh kd} \cos \Theta} \tag{3.46}$$

Step 6: Calculation of Hydrodynamic Pressure

$$\boxed{P = \rho g d_{draft}} \tag{3.47}$$

Step 7: Calculation of Total Pressure

$$\boxed{P = \rho g \left(d_{draft} + \frac{H}{2} \frac{\cosh ks}{\cosh kd} \cos \Theta \right)} \tag{3.48}$$

Step 8: Calculation of Total Force

$$\boxed{F = P.A} \tag{3.49}$$

3.5 Calculation of Pitch Motion

The motion response spectrum need to be studied because of the structure is free to move in waves its motion may be critical near the resonance of the structure. Therefore, it is important to study the overall response of the structure due to the design-wave spectrum as pointed by Chakrabarti (1987). The response amplitude operators are written relating the dynamic-motion of the structure to the wave-forcing function on the structure. The dynamics motion spectrum is obtained from the force motion and force is linear, the conversion is relatively straightforward

Step 1: Calculation of Moment of Inertia and pitch stiffness

The radius of gradation of this platform is 38m, so the moment of inertia can be determine by using equations below

$$\boxed{I_1 = mass\ of\ surge \times radius\ of\ gradation} \tag{3.51}$$

$$\boxed{I_2 = I_1 \times \frac{M_{Added}}{M_{original\ mass}}} \tag{3.52}$$

Pitch period for tension leg platform is range 2-5 sec. In this study, pitch period 2.5 sec was selected because it is an average for Ram Powell platform.

$$\boxed{\omega_n = \sqrt{\frac{K_p}{I}}} \tag{3.53}$$

$$\boxed{\omega_n = 2\pi f} \tag{3.54}$$

$$\boxed{K_p = \omega_n^{\ 2} I_2} \tag{3.55}$$

Step 2: Calculation of Pitch Moment

To calculate pitch moment, the centre of gravity is needed to find and based on the Ram Powell platform design data. The centre of gravity is approximately 3 m below sea water for operation. Centre of gravity will help to find the pitch moment when the surge will be times distance from centre of gravity.

Pitch moment for at particular point

= Surge force x distance at particular point to centre of gravity

This calculation was repeated for 4 columns and 4 pontoons. This total of moment for a certain frequency was repeated starting from 0.05Hz-0.295Hz with interval of 0.05Hz. Each frequency pitch moment will be used to calculate the

Motion Response Spectrum (RAO). This will provide the response in term of spectrum motion and response motion.

3.6 Motion Response Spectrum

The motion response spectrum needs to be studied because of the structure is free to move in waves. Its motion may be critical near the resonance of the structure. Therefore, it is important to study the overall response of the structure due to the design-wave spectrum as pointed by Chakrabarti (1987). The response amplitude operators are written relating the dynamic-motion of the structure to the wave-forcing function on the structure. The dynamics motion spectrum is obtained from the force motion and force is linear, the conversion is relatively straightforward

The motion of the structure in a particular direction, x is uncoupled and can be modelled by a simple linearly damped spring-mass system. The equation of motion is

$$\boxed{m\ddot{x} + C\dot{x} + Kx = F_1 \cos \omega t} \tag{3.61}$$

where F1 is the inertia-force amplitude which is linear with the wave height. Note that Cx is a linear damping term. The displacement, x, is the motion in a particular direction, e.g. surge, sway or heave. $\dot{x}$ and $\ddot{x}$ are corresponding to velocity and acceleration.

The displacement function can be written as

$$\boxed{x(t) = \left| \frac{\frac{Fi}{H/2}}{\sqrt{\left[(K - m\omega^2)^2 + (c\omega)^2\right]}} \right| \eta\beta(t)} \tag{3.62}$$

where β is the phase difference between x(t) and η(t). This relationship can be transform to obtain the motion spectrum in terms of the wave spectrum and RAO.

$$Sx(f) = \left[\frac{\frac{Fi}{H/2}}{\sqrt{\left[\left(K - m\omega^2\right)^2 + \left(c\omega\right)^2\right]}} \right]^2 S(f) \quad (3.63)$$

3.7 Modelling

Modelling was carried out after the completing the literature study. Literature study includes all the final dimensions of the scale model with the calculation of the buoyancy force and environmental force. The scale model has to be fitted in Universiti Teknologi PETRONAS Offshore Lab. The platform was tested in the wave situation at the wave tank or wave flume. This experiment of the response of scale model was analyzed in result and discussion chapter.

Based on the Ram Powell TLP, the model dimension was scaled down to 1:200, the scale dimension of model study are:

- Diameter of column : 10cm
- Column height : 25cm
- Area of deck : 37cm X 37 cm
- Hull : 32cm
- Pontoon : 4cm

The AUTOCAD programme was used to draw this scale platform. The 2D and 3D drawings from the AUTOCAD give the overview of the model. Next steps of model study are to calculate the buoyancy force with the supervision of the supervisor. Below are shown two figures 3.7a and 3.7b that illustrated the scale model. Figures 3.7c illustrates the side view of the model.

The calculation of weight of the platform is based on estimate dimension. Morrison equation was used to determine the force or load applies to the tether. The detail of wave spectrum study was done by collaborate familiarization of the wave flume in the offshore lab.

Model prototype was fabricated after the analysis of surge motion. This model used Perspex material because it provides the buoyancy of the model. The cost for model fabrication is RM315.00 and it follows all design criteria.

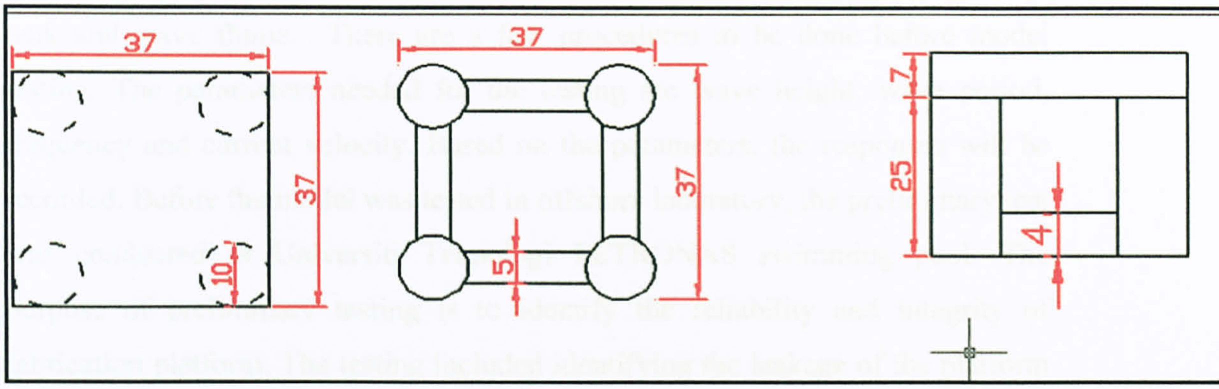


Figure 3.7a: 2D drawing of scale model of TLP

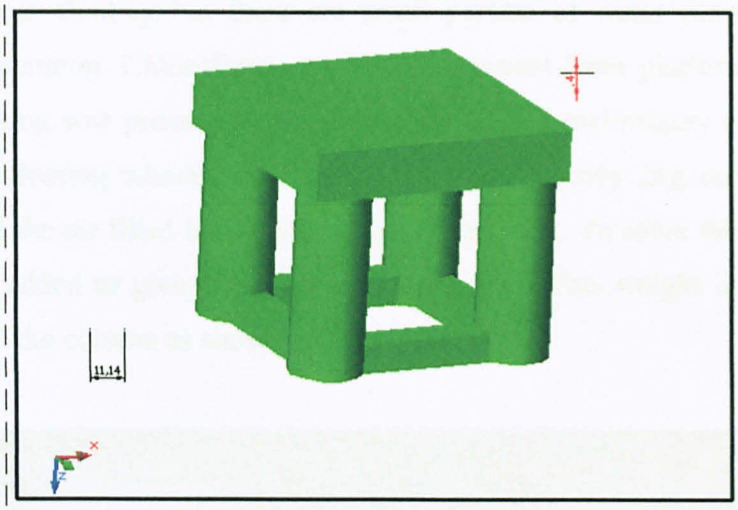


Figure 3.7b: 2D drawing of scale model of TLP

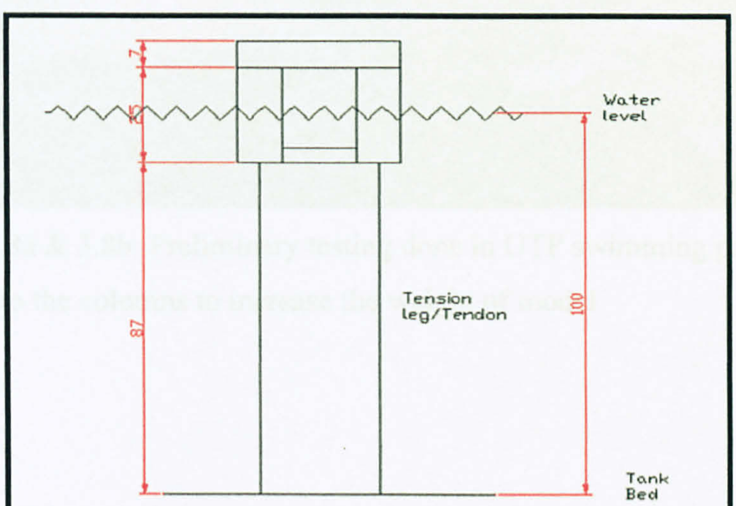


Figure 3.7c: Side view of scale model of TLP

3.8 Model Testing

In Final Year Project (FYP II), the fabricate model was tested in wave tank and wave flume. There are a few procedures to be done before model testing. The parameters needed for the testing are wave height, wave period, frequency and current velocity. Based on the parameters, the responses will be recorded. Before the model was tested in offshore laboratory, the preliminary test was conducted in Universiti Teknologi PETRONAS swimming pool. The purpose of preliminary testing is to identify the reliability and integrity of fabrication platform. The testing included identifying the leakage of the platform due to improper fabrication. From the preliminary test, it was shown that the platform can floating but there are small portion of water passed trough the platform pontoon. Chloroform was used to prevent from platform leakage and model testing was proceeding in laboratory. In this preliminary test, the model was over floating where the weight of platform is only 2kg compared to the volume of the air filled in the columns and pontoons. To solve this problem, the weight is added to give down force to the model. This weight is mainly water filled in to the column as shown in figure below.

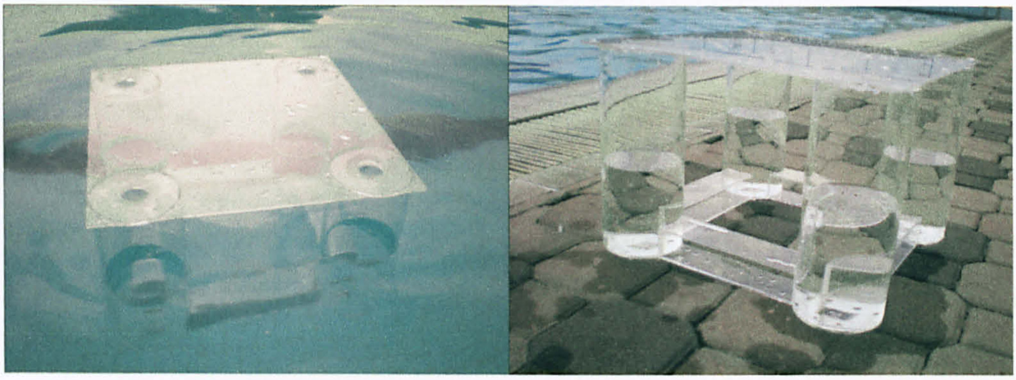


Figure 3.8a & 3.8b: Preliminary testing done in UTP swimming pool. Water was added into the columns to increase the weight of model

3.81 HSE analysis

Before the test is to be carried out in offshore laboratory, it is important to plan the procedures about the testing. It will help if unwanted situation happens. HSE requirements must be followed before entering the laboratories or conducting the experiment and testing. The rules and regulations for entering the laboratories are:

- Laboratory coat must be worn at all time in the lab
- Obey all instructions given by the technicians or lecturer.
- Need permission from Lab Assistant or Lecturers.
- Full covered shoes must be worn at all time.
- Do not touch any equipment control without permission.
- Do report to the technician if there is unusual thing happens.

3.82 Experiment procedure

Apparatus

- Tension leg platform fabrication model
- Concrete cube
- Cable chain
- Measurement apparatus
- Video camera

Testing procedure

1) The apparatus was setup as Figure 3.821 where concrete cube was used as template and cable chain was hooked to the concrete cube and below the platform column. Video camera was placed at strategic location for lighting purposes.

Figure 3.821a & b: Apparatus were assembling before the model testing. The video camera was placed at the wave flume glass.

2) Apparatus was placed in wave flume as Figure 3.5 where apparatus was placed first before wave flume was filled with water. This will help the chain in tension because fabrication model did not have debalasting tank. After that, wave flume was filled with 1m depth of water. Cable chain was in tension.

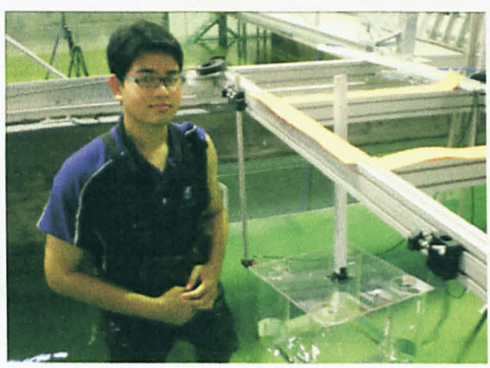


Figure 3.822: Apparatus was place in wave flume.

3) Measurement was done in computer after transferring the video clip of the responses of tension leg platform due to the wave for 90 seconds. Video clip was played on monitor for several times. Estimation of the platform responses was done by putting grid paper as shown in Figure 3.823.There were correction factors that are needed to be considered because of the video scale technical purposes. Measurement of model response was done by taking reference point at column and compare with grid scale.

Figure 3.823: Measurement was taken using the grid paper

4) The platform responses due to wave was measured for every second and result was recorded in the table.

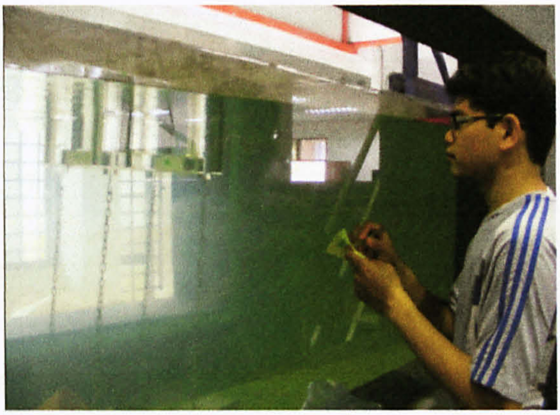


Figure 3.824: The response was measured every second.

5) The frequencies were varied (0.25Hz, 0.35Hz, 0.45Hz and 0.55Hz) with the same wave height for accurate analysis of the platform responses.

CHAPTER 4.0

RESULT AND DISCUSSION

4.1 Analysis of Wave Spectra

4.11 Calculation of Pierson Moskowitz Spectrum

Ram Powell platform

Table 4.111: Ram Powell design criteria

Draft	25 m	Cd	0.65
Diameter Of Column	20.27m	Cm	1.05
Height of pontoon	7.47m	D	980.6m
Wide of pontoon	8.23m	G	9.807
Length of pontoon	54.41m	Hs	11.6m
Total weight of Loading	231MN	Length of deck	74.68m
Length of tether	958.6m		

Buoyancy of Column

$$\boxed{No\ of\ column \times \pi / 4 \times column\, diameter^2 \times draft \times sea\, water\, density \times gravity}$$

$$4 \times \pi / 4 \times 20.27^2 \times 25 \times 9.807 = 325.9552423\text{MN}$$

Buoyancy of pontoons

$$\boxed{No\, of\ pontoons \times pontoon\, wide \times pontoon\, height \times pontoon\, length \times sea\, water\, density \times gravity}$$

$$2 \times 8.23 \times 7.47 \times 54.41 \times 1030 = 135.1551361\,\text{MN}$$

Total Buoyancy = Buoyancy of pontoon + buoyancy of column
= 461.1104MN

Pretension = Total Buoyancy –total weight of loading
= 230.1104MN

Pretension at each tether = Pretension/no of tethers
= 230.1104MN/12 = 19.1758667MN

Draw a PM Spectrum for the frequency range 0.05 to 0.30 Hz, revolving into 25 components

$$\omega_0 = \sqrt{\frac{0.161g}{H_S}} = \sqrt{\frac{0.161(9.807)}{11.6}} = 0.3689\text{rad/sec}$$

$$f_0 = \frac{\omega_0}{2\pi} = \frac{0.3689}{2\pi} = 0.0587\ Hz$$

For a sample of calculation, take f=0.055Hz;

$$s(f) = \frac{\alpha g^2}{2\pi^4} f^{-5} \exp\left[-1.25\left(\frac{f}{f_0}\right)^{-4}\right]$$

$$= \frac{(0.0081)(9.807)^2}{2\pi^4}(0.055)^{-5} \exp\left[-1.25\left(\frac{0.055}{0.0587}\right)^{-4}\right] = 195.7976076$$

Determine the wave heights for the component waves. Calculate the significant height from the spectrum.

We take f=0.005 Hz as for the example of calculation;

$$H(f) = 2\sqrt{2s(f)\Delta f} = 2\sqrt{2(195.797607)(0.01)} = 3.9577530m$$

From excel;

$$\Sigma s(f) = 767.138453$$
$$m_o = \Sigma s(f) \times \Delta f = (767.138453 \times 0.01) = 7.67138$$

$$H_s = 4\sqrt{m_o} = 4\sqrt{7.67138} = \underline{11.08m}$$

m_o is the area under the PM wave Spectrum Graph

To draw the time series, the equations below are being used:

$$\eta(x,t) = \sum_{n=1}^{N} \frac{H(f)}{2} \cos\theta$$

$$\theta = k_n x - \omega_n t + \varepsilon_n = -\omega_n t + \varepsilon_n$$

$$\varepsilon_n = 2\pi R_N$$

$$\omega_n = 2\pi f_{(n)}$$

Calculation of JONSWAP Spectrum

Table 4.112: JONSWAP parameters

Peakeness Parameter	3.3
Shape Parameter	0.07
Xo	4.36
X	100
g	9.81
wo	0.368918
Uw	15
alfa	0.0081

Draw a JONSWAP Spectrum for the frequency range 0.05 to 0.30 Hz, revolving into 25 components. Table 4.112 shows the parameters involve in calculating wave height for each frequency.

$$S(\omega) = \frac{\alpha g^2}{\omega^5} \exp\left[-\frac{5}{4}\left(\frac{\omega_p}{\omega}\right)^4\right] \gamma^r$$

where r is based on below equation

$$r = \exp\left[-\frac{(\omega - \omega_p)^2}{2\,\sigma^2\,\omega_p^2}\right]$$

To draw the time series, the equations below are being used:

$$\eta(x,t) = \sum_{n=1}^{N} \frac{H(f)}{2} \cos\theta$$

$$\theta = k_n x - \omega_n t + \varepsilon_n = -\omega_n t + \varepsilon_n$$

$$\varepsilon_n = 2\pi R_N$$

$$\omega_n = 2\pi f_{(n)}$$

4.12 Results on Pierson-Moskowitz and JONSWAP Spectrum

The result of the wave spectrum by using the P-M theory is shown below:

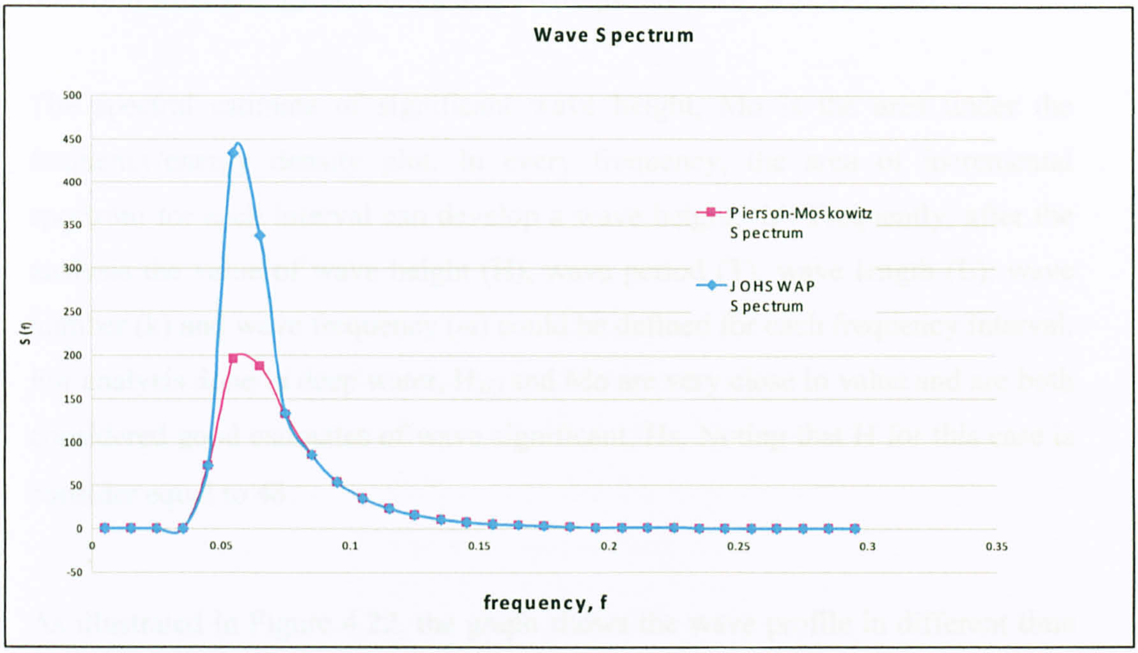
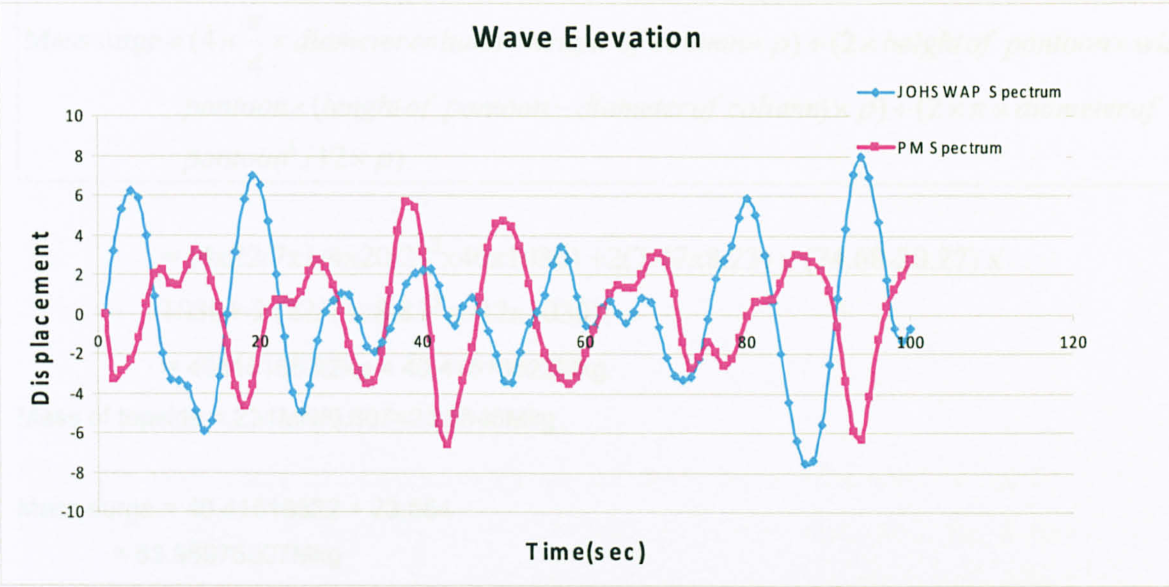


Figure 4.121: Graph Wave spectrum S (f) vs. frequency (Hz)

The graph shows two wave spectra using Pierson Moskowitz (pink line) and JONSWAP spectrum (blue line) versus frequency. From the graph, there is an increment of value of spectrum for JONSWAP spectrum at frequency 0.05 Hz to 0.075 Hz. Average difference in peak of the graph were 3.3. This value varies even for a constant wind speed depending on the duration of the wind and the stage of the growth and the decay of storm. From the graph, shape of graph is similar to the bell shape. This is mathematically true because of spectral analysis was based on the Fourier Transform of the sea surface. The Fourier Transform transforms a time domain signal into a frequency domain representation of that signal. Transformation of any continuous, zero-mean signal into a summation of simple sine waves can be allowed for the Fourier Transform. These sine waves are the components of the sea state, each with a distinct height, frequency, and direction. It indicates that, the spectral analysis method determines the distribution of wave energy and average statistics for each wave frequency by converting the time series of the wave record into a wave spectrum. The spectral approach indicates what frequencies have significant energy content, as well as the direction wave energy is moving at each frequency. The spectral approach indicates what frequencies have significant energy content, as well as the direction wave energy is moving at each frequency.

The spectral estimate of significant wave height, Mo is the area under the frequency/energy density plot. In every frequency, the area of incremental spectrum for each interval can develop a wave height, 'h'. Frequently, after the analysis the value of wave height (H), wave period (T), wave length (L), wave number (k) and wave frequency (ω) could be defined for each frequency interval. For analysis done in deep water, $H_{1/3}$ and Mo are very close in value and are both considered good estimates of wave significant, Hs. Noting that H for this case is consider equal to 4δ.

As illustrated in Figure 4.22, the graph shows the wave profile in different time series of 200s and the analysis of wave profile for different spectrum. This data generated by mathematical spectrum used values of wave frequency, ω.



It is called random wave profile because the analysis includes a random wave generator (R_N). The wave profile was different for each time series because it was computed where k (n) $=2\pi/L$ and L corresponds to the wave length for the *n*th frequency. For this case, the frequency was stipulated from 0.005Hz to 0.295Hz with interval of 0.010.

4.2 Analysis of Surge Motion

Analysis of surge was done by calculating horizontal force. Then, the analysis preceded by finding the motion response spectrum. The motion response spectrum needs to be studied because of the structure is free to move in waves. Its horizontal motion may be critical near the resonance of the structure. Therefore, it is important to study the overall response of the structure due to the design-wave spectrum. The response amplitude operators are written relating the dynamic-motion of the structure to the wave-forcing function on the structure. The dynamics motion spectrum is obtained from the force motion and force is linear, the conversion is relatively straightforward.

4.21 Calculation of Horizontal Force

Below are the calculations to determine the Surge motion, it's starts with calculating total mass surge.

$$\text{Mass surge} = (4\times\frac{\pi}{4}\times diameter\,column \times height\ of\ column \times \rho) + (2\times height\ of\ pontoon \times wide\ of\ pontoon \times (lenght\ of\ pontoon - diameter\ of\ column)\times\rho) + (2\times\pi\times diameter\ of\ pontoon^3 /12\times\rho)$$

$= (4x22/7x1/4x20.27^2x40x1030) + 2(7.47x8.23) x (74.68-20.27) x 1030 + 2 (22/7 x 8.83^3 x /12x1030)$

= 40415165.22kg = 40.41516522Mkg.

Mass of topside = 231MN/9.807=23.5546Mkg

Mass surge = 40.41516522 + 23.554

= 63.96976907Mkg

$restrained\ force = Po / L$

$Stiffness\ surge = ks = Po / L = 230.1104 / 958 = 0.240048381\text{Mn/m}$

$\omega n = \sqrt{}$ (stiffness/mass surge)

= 0.061216693 rad/sec

$Tn = 2pi/\omega n$

$= 102.64sec$

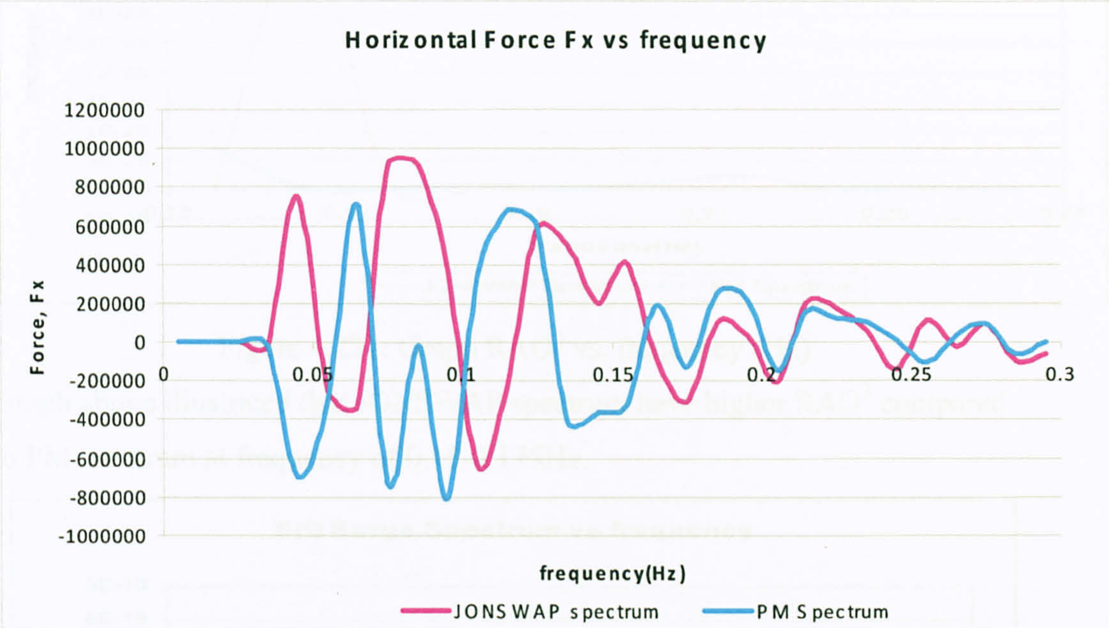


Figure 4.211: Graph Horizontal Force (Fx) vs frequency (Hz)

Graph above illustrates the horizontal forces acting at the platform column at a given frequency. There are two waves spectra were studied in this graph. JONSWAP spectrum gives higher horizontal force rather than PM spectrum. This is basically because the JONSWAP spectrum gives higher energy density than the PM spectrum. The pattern of the graph shows that the horizontal force decreases when frequency increases starting at point 0.15Hz-0.3Hz.

4.22 Surge Motion Response Spectrum

The data and graph for motion response spectrum were calculated based on response amplitude operator (RAO). The stability of the structure is the main concern to the design of tension leg platform. RAO is the formula to determine the stability by illustrated as the effect sea state to the structure. The purpose of calculating the RAO for a platform is to find the response of platform due to surge motion.

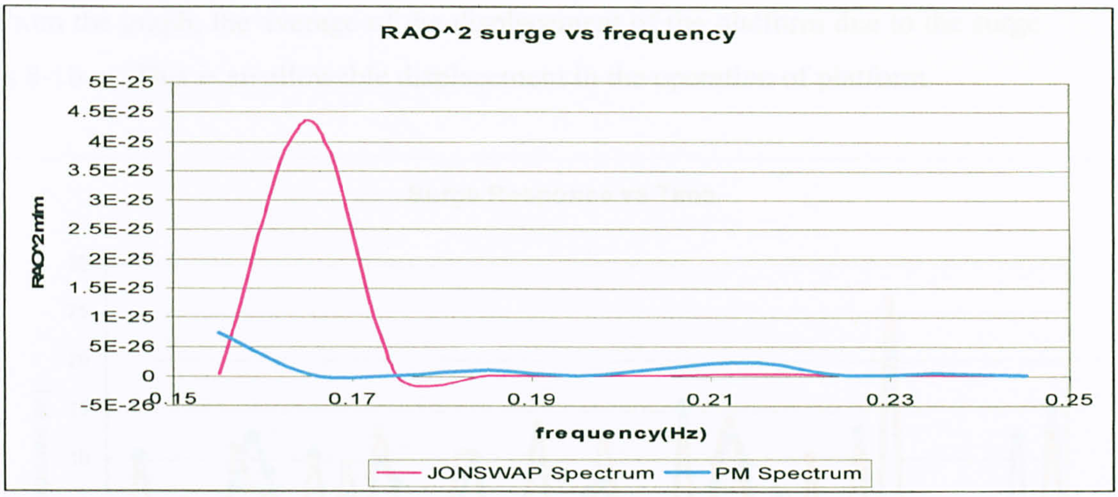


Figure 4.221: Graph RAO^2 vs. frequency (Hz)

Graph above illustrated that JONSWAP spectrum have higher RAO^2 compared to PM spectrum at frequency of 0.15-0.175Hz.

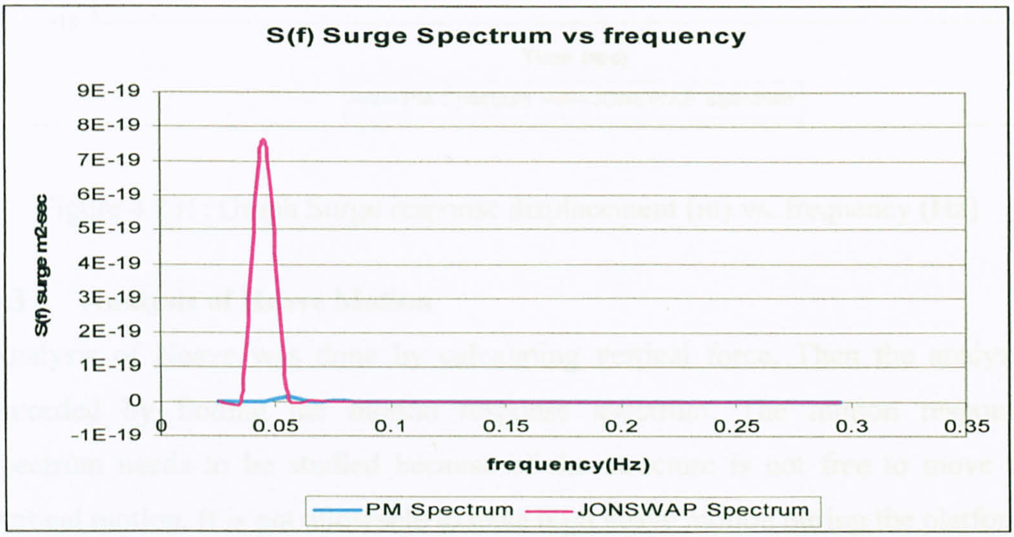


Figure 4.222: Graph S (f) Surge Spectrum vs. frequency (Hz)

Graph above illustrates that the JONSWAP spectrum give high surge spectrum at frequency of 0.03Hz-0.05Hz compared to PM spectrum. This graph helps in term of finding that both spectrums give different energy. After the frequency of 0.05Hz, there are not much different in term of energy.

4.23 Surge Response

From the graph of surge response in Figure 4.231, it can be discussed that the displacement of the platform at particular time is due to the surge motion. This graph is very important to know the reliability of the tension leg platform design.

From the graph, the average of the displacement of the platform due to the surge is 8-10 m. This is an allowable displacement in the operation of platform.

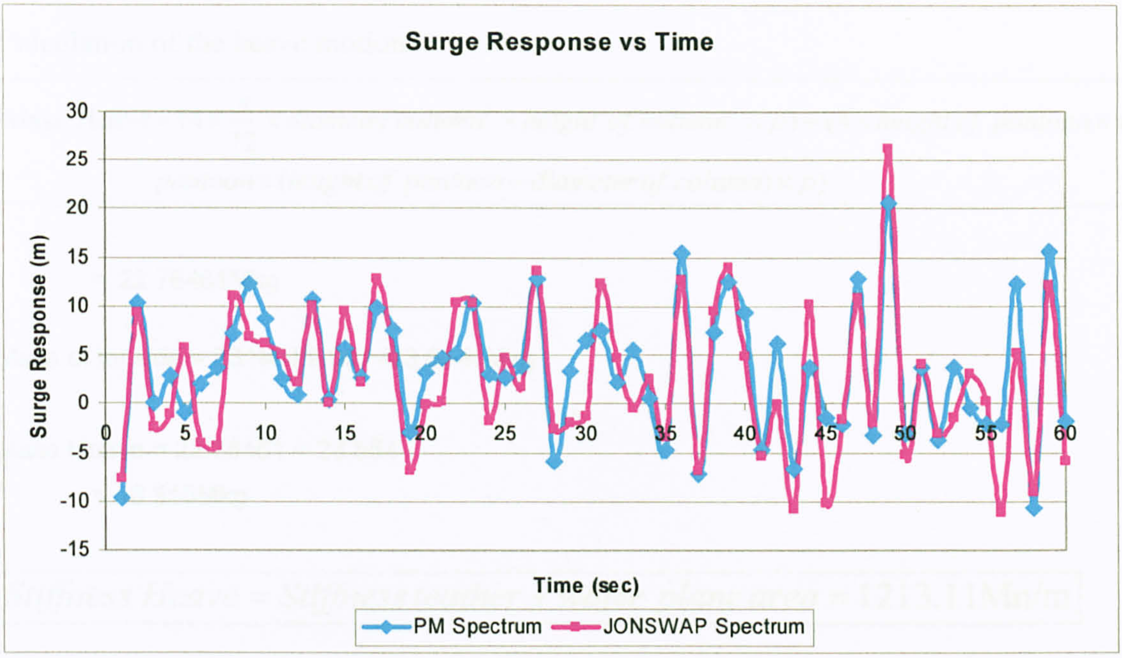


Figure 4.231: Graph Surge response displacement (m) vs. frequency (Hz)

4.3 Analysis of Heave Motion

Analysis of Heave was done by calculating vertical force. Then the analysis preceded by finding the motion response spectrum. The motion response spectrum needs to be studied because of the structure is not free to move in vertical motion. It is not allowable to have high heave motion during the platform operation. Therefore, it is important to study the overall response of the structure due to the design-wave spectrum. The response amplitude operators are written relating the dynamic-motion of the structure to the wave-forcing function on the structure. The dynamics motion spectrum is obtained from the force motion and force is linear, the conversion is relatively straightforward.

4.31 Calculation of Vertical Force

Calculation of the heave motion

$$\text{Mass Heave} = (4 \times \frac{\pi}{12} \times \textit{diameter column}^3 \times \textit{height of column} \times \rho) + (4 \times \textit{height of pontoon} \times \textit{wide of pontoon} \times (\textit{lenght of pontoon} - \textit{diameter of column}) \times \rho)$$

= 22.76461Mkg

Mass of topside = 231MN/9.807=23.5546Mkg

Mass Heave = 22.76461 + 23.554

= 46.318Mkg

$$\textit{Stiffness Heave} = \textit{Stiffness teather} + \textit{water plane area} = 1213.11\text{Mn/m}$$

$\omega n = \sqrt{}$ (stiffness/mass surge)

= 5.11rad/sec

Tn = 2pi/ ωn

= 1.23sec

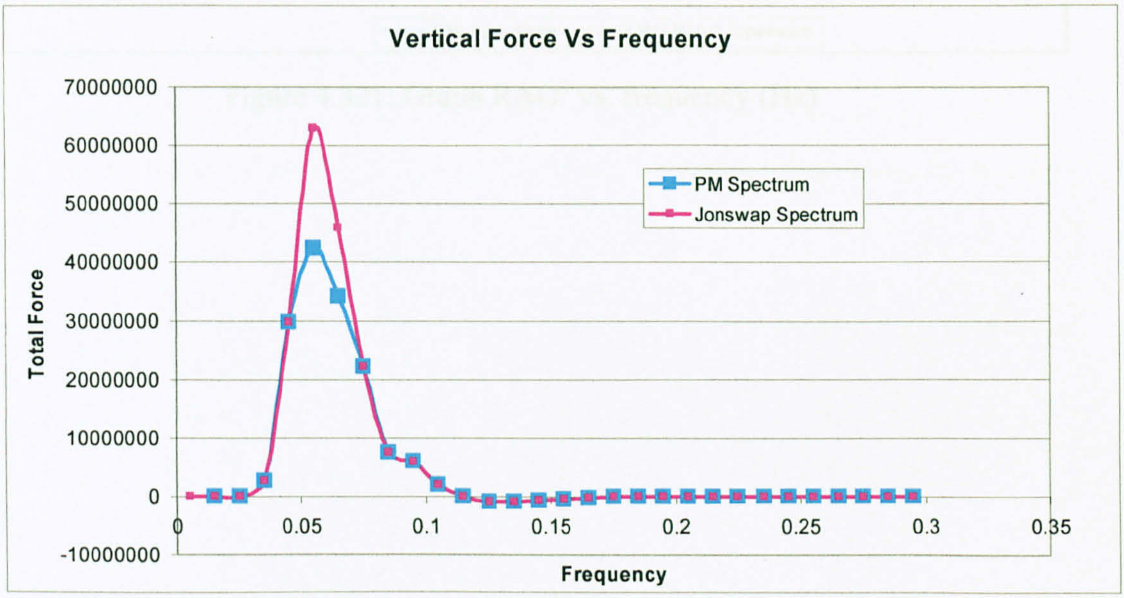


Figure 4.311: Graph Vertical Force Vs Frequency (Hz)

Graph above illustrates the vertical forces acting at the platform at given frequency. There are two waves spectra were studied in this graph. JONSWAP spectrum gives higher vertical force rather than PM spectrum. This was basically because the JONSWAP spectrum gives higher energy density than PM spectrum. The patterns of the graph show that the vertical force achieves the highest peak at frequency 0.02Hz-0.1Hz.

4.32 Heave Motion Response Spectrum

The purpose of calculating the Heave spectrum is to find the height of wave at given frequency. The calculation of Heave spectrum is totally depending on the RAO and P-M spectrum.

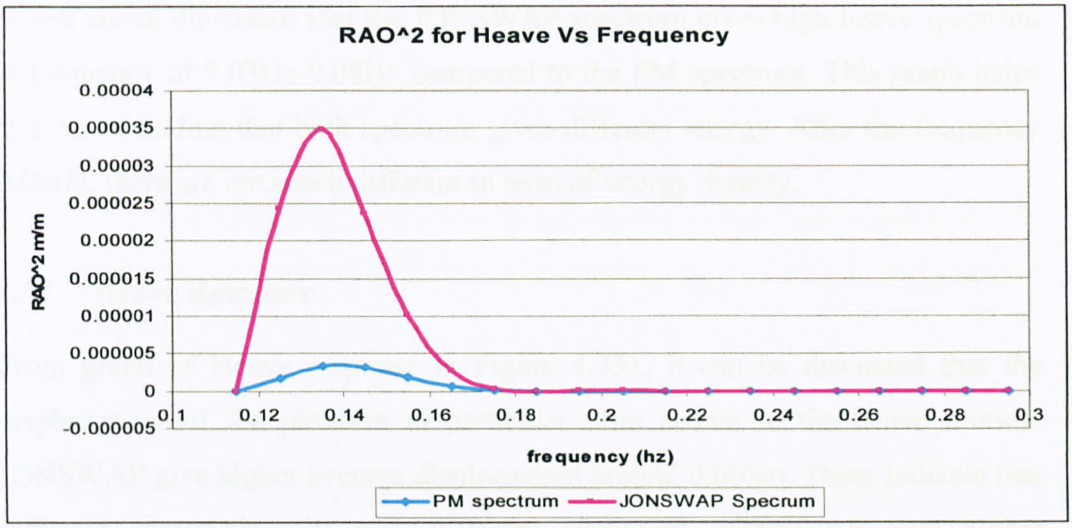


Figure 4.321: Graph RAO^2 vs. frequency (Hz)

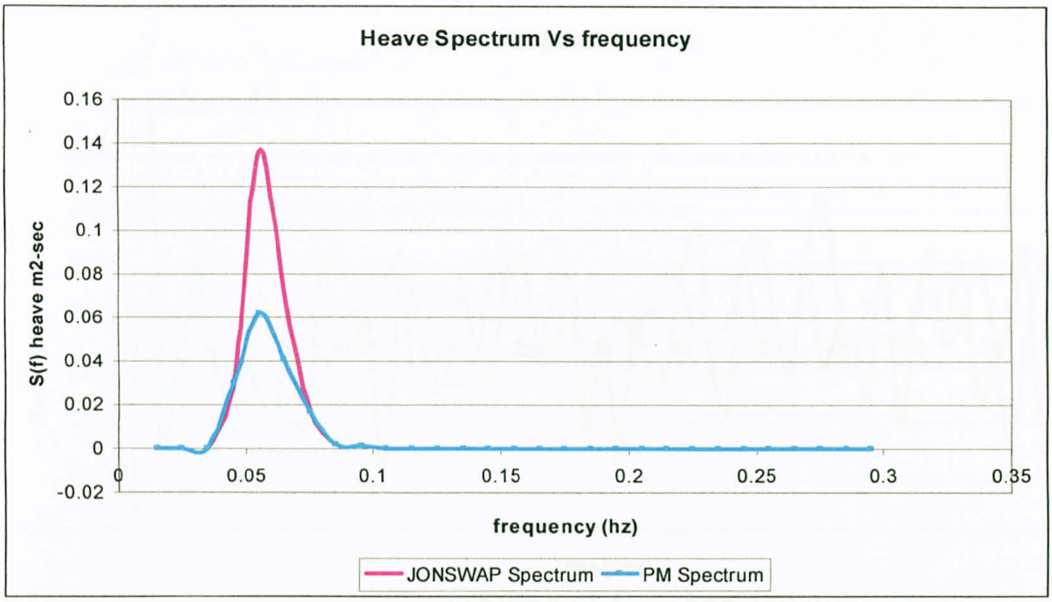


Figure 4.322: Graph S (f) Heave Spectrum vs. frequency (Hz)

Graph above illustrated that the JONSWAP spectrum gives high heave spectrum at frequency of 0.03Hz-0.08Hz compared to the PM spectrum. This graph helps in term of finding that both spectrum gives different energy. After the frequency 0.08Hz, there are not much different in term of energy density.

4.33 Heave Response

From graph of Heave response in Figure 4.331, it can be discussed that the displacement of the platform at particular time is due to the heave motion. JONSWAP give higher average displacement around 0.005m. These indicate that different spectrums will give different responses. JONSWAP give higher displacement rather than PM spectrum. The average displacement of the platform due to the surge is 0.005m. This is an allowable vertical displacement in the operation of platform.

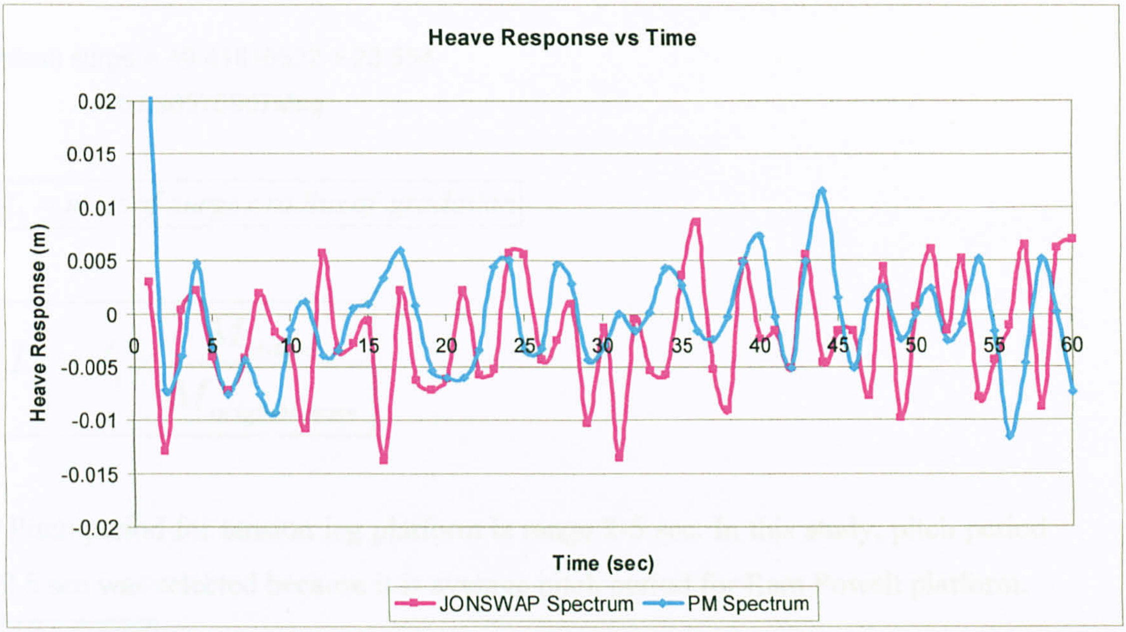


Figure 4.331: Graph Heave response displacement (m) vs. frequency (Hz)

4.4 Analysis of Pitch Motion

Analysis of Pitch motion was done by calculating moment of horizontal force at the location of the centre of gravity. Then the analysis preceded by finding the motion response spectrum. Lastly, the pitch response was calculated based on the pitch spectrum. Result for this analysis will indicate the integrity of the platform from pitch moment.

4.41 Calculation of Pitch motion

Below are the calculation steps to find the pitch stiffness. The moment calculation was done using Microsoft Excel 2003. It is placed in the appendix chapter.

$$\text{Mass surge} = (4 \times \frac{\pi}{4} \times diameter\ column \times height\ \ of\ column \times \rho) + (2 \times height\ of\ \ pontoon \times wide\ of\ \ pontoon \times (lenght\ of\ \ pontoon - diameter\ of\ column) \times \rho) + (2 \times \pi \times diameter\ of\ \ pontoon^3 / 12 \times \rho)$$

= (4x22/7x1/4x20.27^{2}x40x1030) +2(7.47x8.23) x (74.68-20.27) x 1030+ 2 (22/7 x 8.83^3 x /12x1030)

= 40415165.22kg = 40.41516522Mkg.

Mass of topside = 231MN/9.807=23.5546Mkg

Mass surge = 40.41516522 + 23.554

= 63.96976907Mkg

$$\boxed{I_1 = mass\ of\ surge \times radius\ of\ gradation}$$

$$\boxed{I_2 = I_1 \times \frac{M_{Added}}{M_{original\ mass}}}$$

Pitch period for tension leg platform is range 2-5 sec. In this study, pitch period 2.5 sec was selected because it is average pitch period for Ram Powell platform.

$$\boxed{\omega_n = \sqrt{\frac{K_p}{I}}}$$

$$\boxed{\omega_n = 2\pi f}$$

$$\boxed{K_p = \omega_n^{\ 2} I_2}$$

4.42 Pitch Motion Response Spectrum

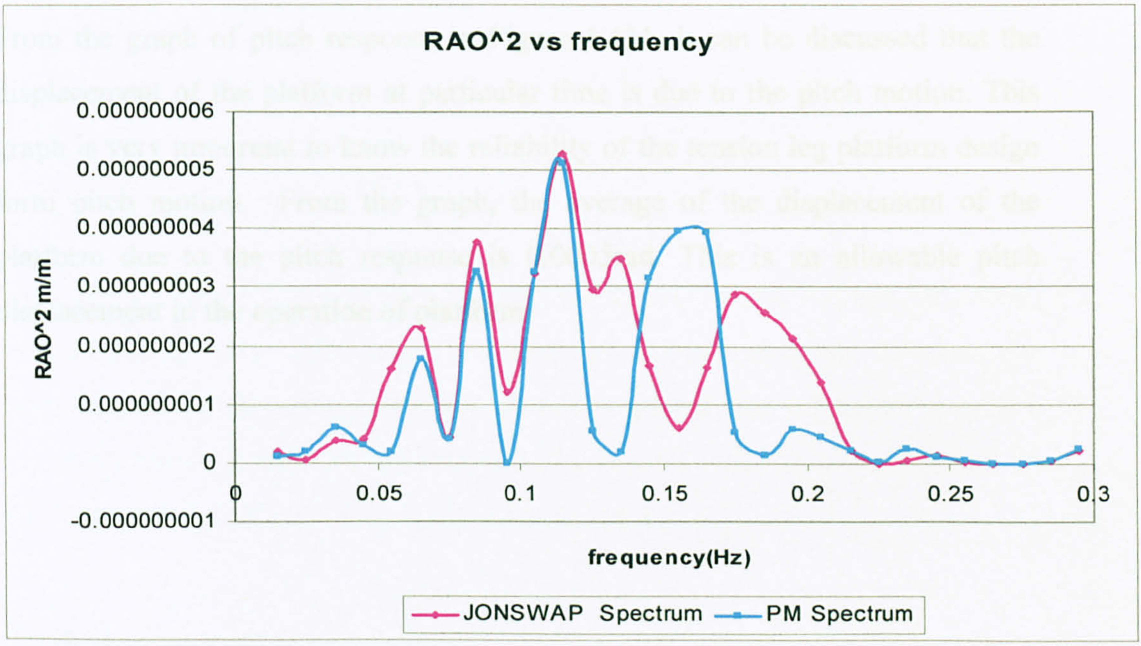


Figure 4.421: Graph RAO^2 vs. frequency (Hz)

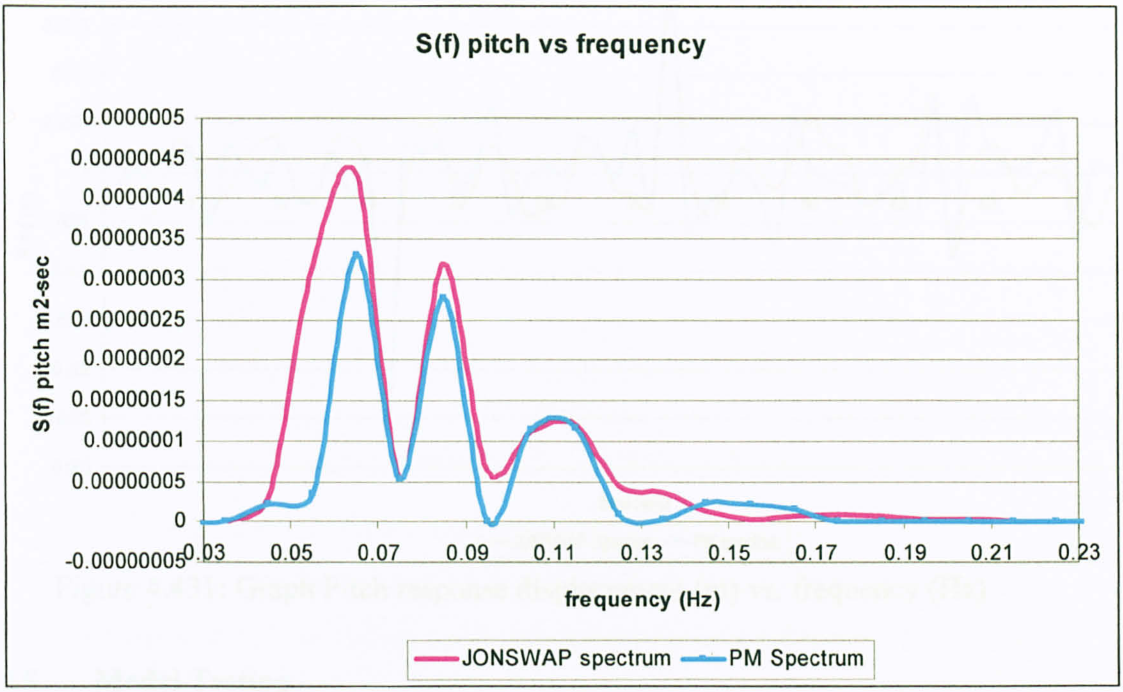


Figure 4.422: Graph S (f) Heave Spectrum vs. frequency (Hz)

The graph above illustrates that the JONSWAP spectrum give high pitch spectrum compared to PM spectrum. This graph helps in term of finding that both spectra give different energy density.

4.43 Pitch Response

From the graph of pitch response in Figure 4.431, it can be discussed that the displacement of the platform at particular time is due to the pitch motion. This graph is very important to know the reliability of the tension leg platform design form pitch motion. From the graph, the average of the displacement of the platform due to the pitch response is 0.0005rad. This is an allowable pitch displacement in the operation of platform

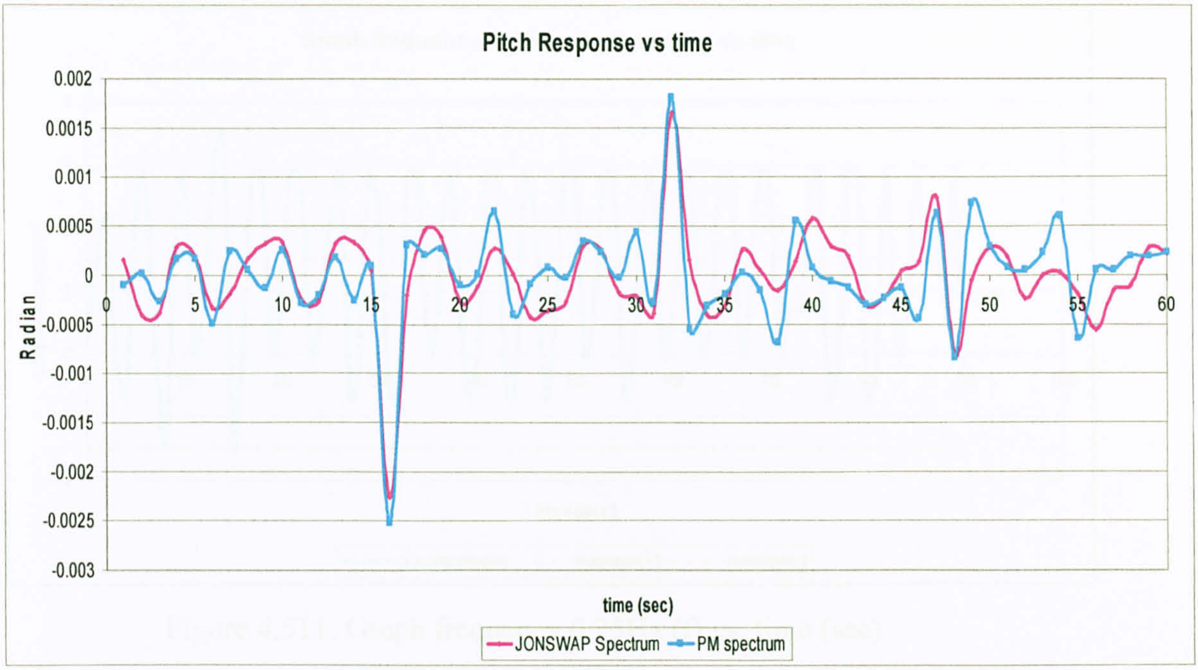


Figure 4.431: Graph Pitch response displacement (m) vs. frequency (Hz)

4.5 Model Testing

4.51 Result of model testing

Model testing was carried a few times after the literature study was done. Based on the experiment, below is a table consisting of the results for the experiment. This test was carried in wave flume. The parameters that are included in this test are:

Frequency of wave flume = 0.25 Hz. 0.35Hz, 0.45Hz and 0.55Hz
Water depth = 1.0 m
Wave height = 0.05 m

The test was carried a few times consisting on regular waves. For regular waves, the frequencies were varied to get accurate and convincing result. The test was carried for 90sec for every frequencies and response was tabulated in tables. Below are shown graphs for model testing for water depth 1m, wave height 0.05 and frequency 0.25Hz, 0.35Hz, 0.45Hz and 0.55Hz.

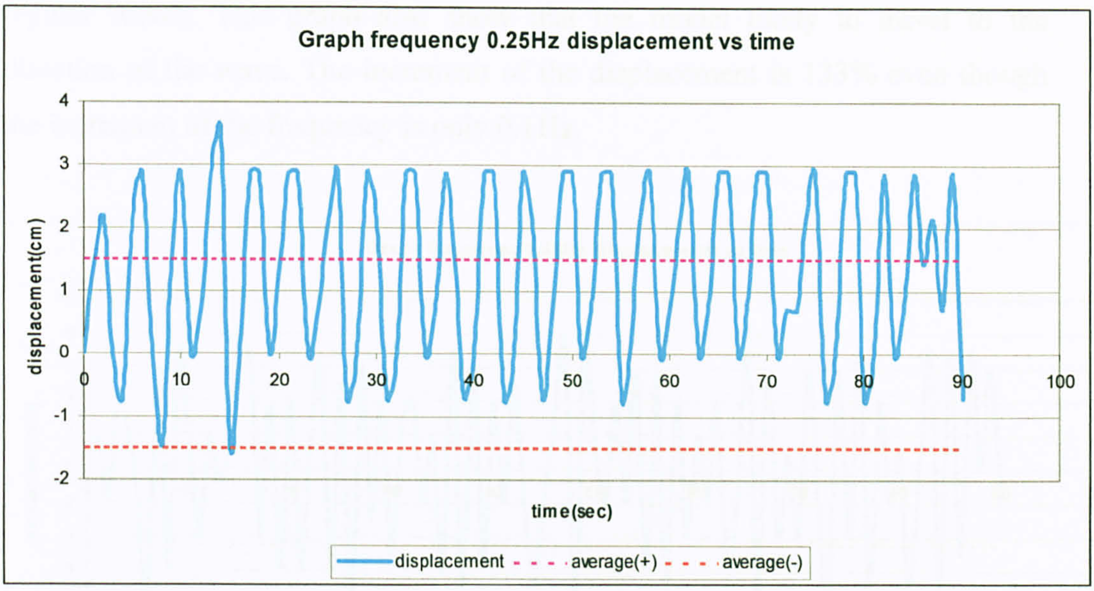


Figure 4.511: Graph frequency 0.25Hz (f) vs. time (sec)

The graph shows that the average of the response or displacement of model due to wave was 1.5cm. The red and pink are lines that indicate the average of the responses. This was result from 5cm wave height and 0.25Hz frequency of regular waves. The graph also shows that the model is likely to travel to the direction of the wave rather than going back to the original position. This is true because the response is higher in positive amplitude rather than negative amplitude.

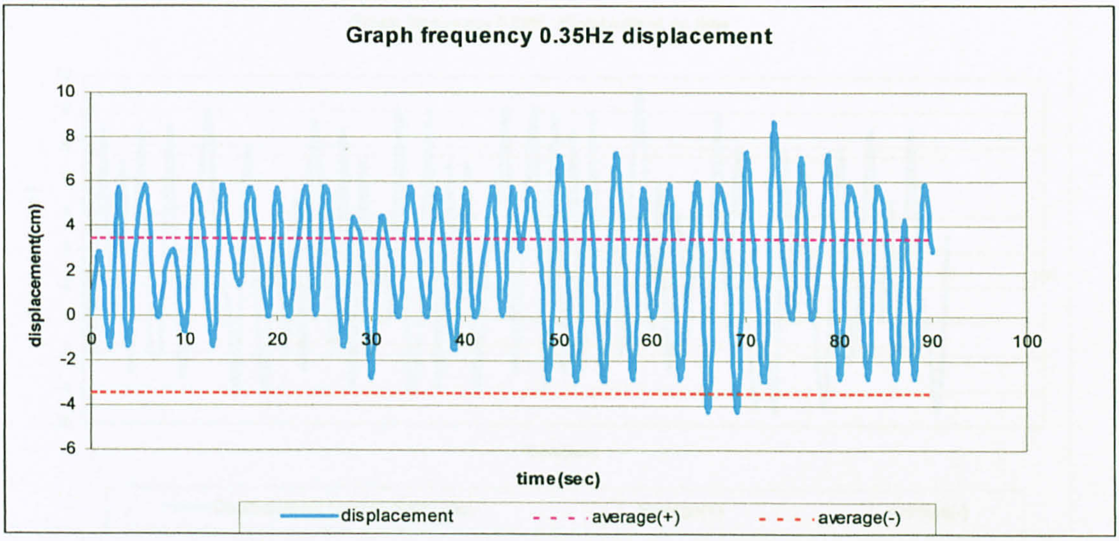


Figure 4.512: Graph frequency 0.35Hz (f) vs. time (sec)

The graph above shows that the average of the response or displacement of model due to wave is 3.5cm. The red and pink are lines that indicate the average of the responses. This resulted from 5cm wave height and 0.35Hz frequency of regular waves. This graph also show that the model likely to travel to the direction of the wave. The increment of the displacement is 133% even though the increment of the frequency is only 0.1Hz.

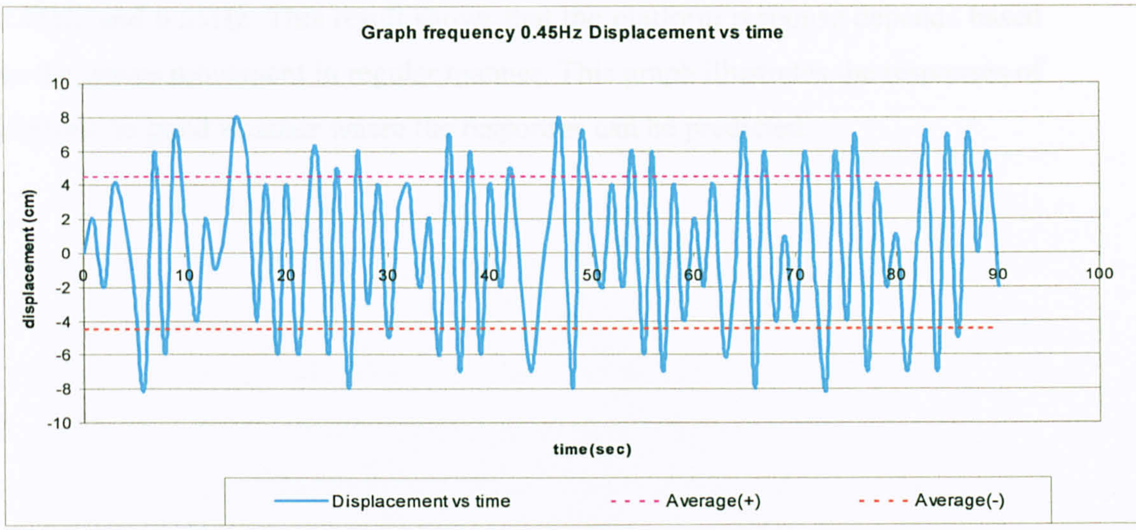


Figure 4.513: Graph frequency 0.45Hz (f) vs. time (sec)

For graph frequency 0.45Hz, the average of displacement is 4.3cm. This is a minimal increment in displacement. The percentage of increment is 23%. This shows that the increment of the displacement of model does not vary with frequency.

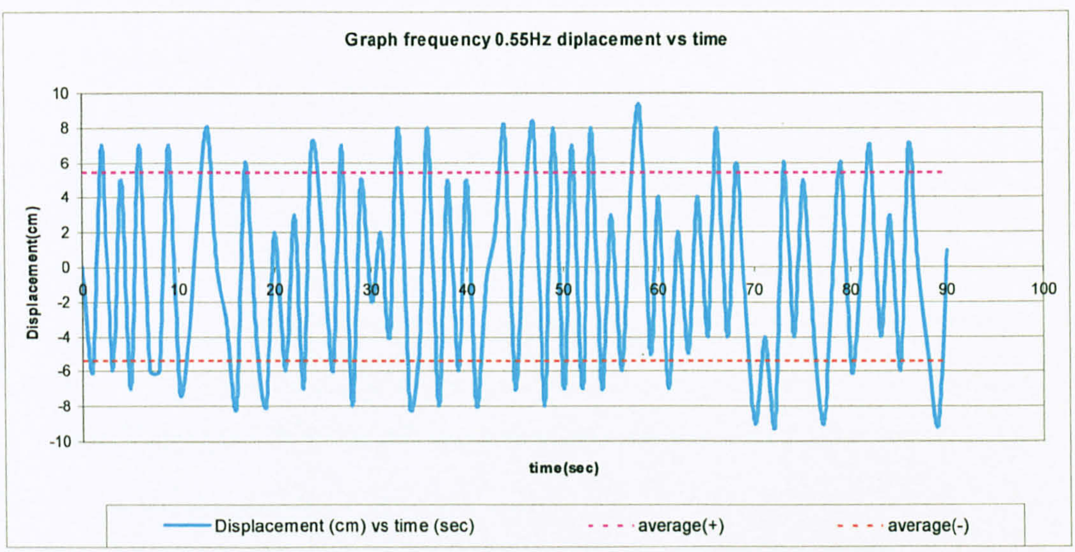


Figure 4.514: Graph frequency 0.55Hz (f) vs. time (sec)

In the last graph, the average of displacement is 5.2cm. This is indicated by the red and pink lines in the graph above. The increment is only 21 %. This can be concluded that the increment of model displacement will ~~decreased~~ when the frequency increases.

From all graphs, the average response is different for frequency 0.25Hz, 0.35Hz, 0.45Hz and 0.55Hz. This result shows that the platform response depends based on the waves movement in regular manner. This graph illustrates the responses of platform in good weather where the responses can be predicted.

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CHAPTER 5
CONCLUSION AND RECOMENDATION

Compliant structures are classified as important class of offshore structure and have been studied over the past two decades. The response of TLP under random sea wave loads was investigated. The time history of random wave is generated based on Pierson-Moskowitz spectrum and it acts on the structure in arbitrary direction. Morison equation is calculated to determine the hydrodynamic forces. This analysis is necessary to check the response of a design TLP under environmental loads. The response of the platform was analyzed for surge, heave and pitch motion. The P-M spectrum is analyzed with the JONSWAP spectrum.

The dynamic load that arises from natural phenomena such as waves cannot be adequately described by sinusoidal or other periodic functions. The pattern of loading with does not repeat itself at regular seas. It is necessary to resort to Spectral Density Function. Spectral Density Function such as the JONSWAP Spectrum is usually for sea that is not fully developed and always characterized by a high wind speed, whereas Pierson Moskowitz Spectrum is usually for a fully developed sea. For JONSWAP and Pierson Moskowitz spectrum, the understanding from the case study is such that the system response is highly tied in with the energy. Therefore, the energy density for JONSWAP spectrum is higher than PM spectrum, thus the responses of tension leg platform is higher if using the JONSWAP spectrum approximate 10-15% compared to PM spectrum.

The scale model is tested in the offshore laboratory to determine the response of the TLP due to the wave spectrum. Based on the result, it will conclude that response of tension leg platform is different for different frequency

5.1 Recommendation

For this study, the recommendation for enhancing the future study on responses of tension leg platform due to wave spectrum is to consider the hydrodynamic force on tethers. This is because; hydrodynamic force is significant to the responses of platform. In the case study, it is good to calculate the tension of the tethers because it plays significant amount of force.

To make the research more significant and accurate, there should be some modification on the research. Provided below are the modifications needed to improve the study

- To get data such as total mass, radius of gradation and significant height from the company that operates the platform. This is due to the data resources that are not accurate and have to make assumption for certain parameters.
- To study on yaw, roll and sway to complete six degree of freedom of the platform.
- To use deep water platform software like SACS or other tools for better analysis of the platform.
- Enhance the numerical analysis for new generation of tension leg platform such as MOSES, and Seastar TLP.
- In term of laboratories activity, it is good to have better equipment for measurement and data collections.
- For the model testing, irregular wave testing must be implemented because it shows the actual condition at the middle of sea.

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APPENDICES

Table 1: Data for PM wave spectrum

f	f/fo	s(f)	Area
0.005	0.08516	0	1E-124
0.015	0.25547	2E-122	7.8E-15
0.025	0.42578	1.6E-12	0.00239
0.035	0.5961	0.47748	0.36407
0.045	0.76641	72.3363	1.34096
0.055	0.93673	195.856	1.9164
0.065	1.10704	187.425	1.59567
0.075	1.27735	131.709	1.0823
0.085	1.44767	84.7507	0.69289
0.095	1.61798	53.8277	0.44243
0.105	1.7883	34.6586	0.28743
0.115	1.95861	22.8275	0.1912
0.125	2.12892	15.4121	0.13036
0.135	2.29924	10.6597	0.091
0.145	2.46955	7.54054	0.06493
0.155	2.63986	5.44504	0.04726
0.165	2.81018	4.00602	0.03502
0.175	2.98049	2.99756	0.02638
0.185	3.15081	2.27757	0.02016
0.195	3.32112	1.7547	0.01562
0.205	3.49143	1.36904	0.01225
0.215	3.66175	1.0805	0.00971
0.225	3.83206	0.8618	0.00778
0.235	4.00238	0.69404	0.00629
0.245	4.17269	0.56392	0.00513
0.255	4.343	0.46197	0.00422
0.265	4.51332	0.38133	0.00349
0.275	4.68363	0.31699	0.00291
0.285	4.85394	0.26524	0.00244
0.295	5.02426	0.22329	4.20201
	840.179	Total Area	10.8953

Table 2: Data for JONSWAP wave spectrum vs. frequency

f	w	T	s(w)	Area	s(f)
0.005	0.03142	0.07	0	2E-125	0
0.015	0.09425	0.07	4E-123	1.2E-15	2.4E-122
0.025	0.15708	0.07	2.5E-13	0.00038	1.56E-12
0.035	0.21991	0.07	0.07604	0.05824	0.477772
0.045	0.28274	0.07	11.5724	0.4027	72.71141
0.055	0.34558	0.07	68.9669	0.61368	433.3317
0.065	0.40841	0.09	53.7697	0.37481	337.8448
0.075	0.47124	0.09	21.1931	0.17345	133.1604
0.085	0.53407	0.09	13.4968	0.11035	84.80297
0.095	0.5969	0.09	8.57219	0.07046	53.86069
0.105	0.65973	0.09	5.51946	0.04577	34.67978
0.115	0.72257	0.09	3.63534	0.03045	22.84151
0.125	0.7854	0.09	2.45441	0.02076	15.42148
0.135	0.84823	0.09	1.69758	0.01449	10.6662
0.145	0.91106	0.09	1.20085	0.01034	7.545151
0.155	0.97389	0.09	0.86714	0.00753	5.448375
0.165	1.03673	0.09	0.63797	0.00558	4.008474
0.175	1.09956	0.09	0.47737	0.0042	2.999398
0.185	1.16239	0.09	0.36271	0.00321	2.27896
0.195	1.22522	0.09	0.27944	0.00249	1.755772
0.205	1.28805	0.09	0.21802	0.00195	1.369875
0.215	1.35088	0.09	0.17207	0.00155	1.081164
0.225	1.41372	0.09	0.13724	0.00124	0.86233
0.235	1.47655	0.09	0.11053	0.001	0.694462
0.245	1.53938	0.09	0.08981	0.00082	0.564264
0.255	1.60221	0.09	0.07357	0.00067	0.46225
0.265	1.66504	0.09	0.06073	0.00056	0.381563
0.275	1.72788	0.09	0.05048	0.00046	0.317184
0.285	1.79071	0.09	0.04224	0.00039	0.2654
0.295	1.85354	0.09	0.03556	0.97903	0.22343
0.305	1.91637	0.09	0.03011	0.00015	0.189173
0.315	1.9792	0.09	0.02563	0.00013	0.161026
0.325	2.04204	0.09	0.02192	0.0099	0.137755
0.335	2.10487	0.09	0.01884	0.02808	0.118404
		195.77	Total Area	2.93654	

T	η(0,T)	T	η(0,T)	T	η(0,T)	T	η(0,T)	T	η(0,T)
1	7.31E-07	45	-3.41862	89	-1.00894	133	-0.46047	177	4.53503
2	0.058472	46	-5.25199	90	0.338278	134	-2.54791	178	3.019819
3	0.244202	47	-5.45074	91	1.373546	135	-3.72276	179	1.111613
4	-0.28507	48	-4.32278	92	2.056071	136	-2.93622	180	-0.25568
5	-0.06763	49	-2.60845	93	2.185429	137	-1.10279	181	-1.49949
6	1.430076	50	-0.79757	94	1.672805	138	0.266099	182	-3.07318
7	2.614719	51	1.078892	95	1.041053	139	0.626687	183	-3.71394
8	2.177689	52	3.003512	96	0.400894	140	-0.16602	184	-2.20987
9	0.511214	53	4.689095	97	-0.85273	141	-1.92078	185	0.386032
10	-1.68031	54	5.411902	98	-2.21263	142	-3.18272	186	2.224868
11	-3.99949	55	4.441551	99	-2.06658	143	-2.31398	187	2.747539
12	-5.34684	56	2.522426	100	-0.53161	144	0.462195	188	2.220122
13	-4.52952	57	1.606029	101	0.341741	145	3.451828	189	0.99083
14	-2.09044	58	1.772926	102	-0.06592	146	5.265112	190	-0.35404
15	0.323556	59	0.746074	103	-0.2401	147	5.443226	191	-1.3847
16	2.031485	60	-2.17741	104	0.290653	148	4.302683	192	-2.06202
17	3.159749	61	-4.85968	105	0.054721	149	2.585165	193	-2.18231
18	3.564509	62	-5.87753	106	-1.45191	150	0.773813	194	-1.66402
19	3.376606	63	-5.77495	107	-2.62021	151	-1.10381	195	-1.03385
20	3.128943	64	-4.72445	108	-2.16194	152	-3.02792	196	-0.38954
21	2.543275	65	-2.48746	109	-0.4853	153	-4.7067	197	0.872941
22	1.017173	66	0.064406	110	1.710808	154	-5.41079	198	2.223205
23	-0.75627	67	2.113956	111	4.026546	155	-4.41884	199	2.052096
24	-1.69772	68	3.905953	112	5.351294	156	-2.50052	200	0.511684
25	-2.04617	69	5.150403	113	4.504895	157	-1.60478		
26	-2.35126	70	4.963902	114	2.055876	158	-1.77239		
27	-2.27194	71	3.784445	115	-0.35015	159	-0.71778		
28	-1.72209	72	2.681852	116	-2.04971	160	2.219342		
29	-1.41171	73	1.384117	117	-3.17013	161	4.883715		
30	-1.56227	74	-0.7675	118	-3.56471	162	5.881628		
31	-1.62099	75	-3.16106	119	-3.37306	163	5.768357		
32	-1.06159	76	-4.62931	120	-3.12532	164	4.702546		
33	0.435054	77	-4.54668	121	-2.52976	165	2.453527		
34	2.52283	78	-3.04487	122	-0.99278	166	-0.09449		
35	3.71986	79	-1.13361	123	0.774921	167	-2.13805		
36	2.95683	80	0.240882	124	1.704212	168	-3.92768		
37	1.125958	81	1.480513	125	2.050247	169	-5.1582		
38	-0.25453	82	3.054586	126	2.353919	170	-4.95221		
39	-0.62899	83	3.718945	127	2.266781	171	-3.76844		
40	0.148005	84	2.240808	128	1.714931	172	-2.66836		
41	1.896776	85	-0.35427	129	1.411418	173	-1.36194		
42	3.177914	86	-2.20973	130	1.565037	174	0.799622		
43	2.340306	87	-2.74815	131	1.618576	175	3.188146		
44	-0.42088	88	-2.23242	132	1.048576	176	4.638751		

Table 3: Wave elevation data for JONSWAP and PM Spectrum

F(n)	RAO	RAO2 PM Spectrum	RAO	RAO2 JONSWAP spectrum
0.005	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
0.015	9.416E-10	8.86534E-19	6.79752E-10	4.62063E-19
0.025	1.03E-10	1.05994E-20	-1.5739E-10	2.47711E-20
0.035	-9.493E-12	9.01163E-23	-1.1498E-11	1.32194E-22
0.045	2.171E-12	4.71131E-24	1.50818E-12	2.27461E-24
0.055	-3.9E-11	1.5235E-21	2.0208E-10	4.08355E-20
0.065	3.03E-12	9.18205E-24	2.4467E-12	5.98631E-24
0.075	-2.2E-12	4.96199E-24	4.9534E-13	2.45361E-25
0.085	-3.8E-13	1.46882E-25	4.2178E-13	1.77897E-25
0.095	-2.2E-13	5.02012E-26	-1.315E-11	1.72949E-22
0.105	6.02E-13	3.62099E-25	2.5332E-13	6.41732E-26
0.115	-6.9E-12	4.81536E-23	-1.554E-13	2.41358E-26
0.125	1.05E-13	1.10219E-26	9.4482E-14	8.92675E-27
0.135	-7.8E-14	6.08283E-27	-8.324E-14	6.92851E-27
0.145	-1.4E-13	2.01094E-26	6.4603E-14	4.17354E-27
0.155	6.74E-14	4.54456E-27	-5.833E-14	3.40201E-27
0.165	1.96E-12	3.82303E-24	1.9588E-13	3.8368E-26
0.175	-4.8E-14	2.29054E-27	4.0655E-14	1.6528E-27
0.185	1.14E-13	1.29642E-26	3.783E-14	1.43108E-27
0.195	-3.2E-14	1.00982E-27	-3.632E-14	1.31893E-27
0.205	-1.7E-13	2.9586E-26	3.3793E-14	1.14196E-27
0.215	6.28E-14	3.94497E-27	8.3531E-14	6.97735E-27
0.225	-2.4E-14	5.87377E-28	1.3312E-13	1.7721E-26
0.235	-2.1E-14	4.57756E-28	2.257E-14	5.0939E-28
0.245	-4E-14	1.5648E-27	-5.949E-14	3.53908E-27
0.255	3.41E-14	1.164E-27	2.3876E-14	5.70084E-28
0.265	1.3E-13	1.69135E-26	2.5596E-13	6.55153E-26
0.275	-2.1E-14	4.40441E-28	-1.572E-14	2.47202E-28
0.285	4.39E-14	1.92909E-27	1.5072E-14	2.27177E-28
0.295	-3.5E-14	1.2012E-27	-2.714E-14	7.3657E-28

Table 4: Surge spectrum data RAO²

Table 5: Surge response data

T	n(0,T) PM Spectrum	n(0,T) JONSWAP	T	n(0,T) PM	n(0,T) JONSWAP
1	7.31E-07	-6.757700771	31	8.59825277	-1.6209901
2	0.058472	5.080922833	32	6.65899833	-1.0615891
3	0.244202	2.039326791	33	-3.16488699	0.43505442
4	-0.28507	-3.76255479	34	0.770403	2.52283012
5	-0.06763	1.238045849	35	2.14438964	3.7198595
6	1.430076	-7.059397698	36	14.8614482	2.95683035
7	2.614719	0.835816148	37	-10.0157959	1.12595798
8	2.177689	0.82566296	38	2.78766267	-0.2545347
9	0.511214	6.373947268	39	7.97595128	-0.62899
10	-1.68031	1.144078029	40	7.20885069	0.14800477
11	-3.99949	7.140626461	41	-7.51418812	1.89677561
12	-5.34684	-0.592936351	42	0.97526421	3.17791404
13	-4.52952	3.649123361	43	-12.1741266	2.34030623
14	-2.09044	9.122791441	44	1.59025205	-0.4208837
15	0.323556	1.293946102	45	1.40010356	-3.4186246
16	2.031485	5.593279566	46	-6.62138273	-5.2519854
17	3.159749	5.177906608	47	5.11131399	-5.4507427
18	3.564509	8.676322501	48	0.26490038	-4.322784
19	3.376606	-12.5537078	49	28.4265532	-2.6084528
20	3.128943	0.93153322	50	0.5174014	-0.7975663
21	2.543275	-0.043465472	51	0.58037261	1.07889175
22	1.017173	5.082397683	52	-0.4005146	3.00351211
23	-0.75627	6.428794884	53	6.97340067	4.68909474
24	-1.69772	1.873826676	54	-1.02980498	5.41190243
25	-2.04617	-0.337863649	55	-8.40490828	4.44155085
26	-2.35126	5.048855099	56	-11.5765793	2.52242613
27	-2.27194	3.073224313	57	13.81921	1.60602859
28	-1.72209	1.480604226	58	-15.8651712	1.77292582
29	-1.41171	-0.942480284	59	14.5273925	0.74607352
30	-1.56227	-7.909274739	60	-9.87013672	-2.177415

Table 6: Heave spectrum data RAO^2

F(n)	RAO	RAO2 PM Spectrum	RAO	RAO2 JONSWAP spectrum
0.005	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
0.015	0.025268	0.000638496	0.02526847	0.000638496
0.025	0.024091	0.000580384	0.02409116	0.000580384
0.035	0.022494	0.000505987	0.02249416	0.000505987
0.045	0.020372	0.000415034	0.02037237	0.000415034
0.055	0.017736	0.000314563	0.01773593	0.000314563
0.065	0.014673	0.000215309	0.01467342	0.000215309
0.075	0.011342	0.000128635	0.01134173	0.000128635
0.085	0.004768	2.27376E-05	0.0047684	2.27376E-05
0.095	0.004788	2.29257E-05	0.00478808	2.29257E-05
0.105	0.002078	4.31911E-06	0.00207825	4.31911E-06
0.115	3.03E-05	9.17201E-10	3.0285E-05	9.17201E-10
0.125	0.001257	1.58058E-06	0.00125721	1.58058E-06
0.135	0.001811	3.27844E-06	0.00181065	3.27844E-06
0.145	0.001774	3.14535E-06	0.00177351	3.14535E-06
0.155	0.001366	1.86514E-06	0.0013657	1.86514E-06
0.165	0.000822	6.76142E-07	0.00082228	6.76142E-07
0.175	0.000333	1.1091E-07	0.00033303	1.1091E-07
0.185	4.19E-06	1.75853E-11	4.1935E-06	1.75853E-11
0.195	0.000146	2.13469E-08	0.00014611	2.13469E-08
0.205	0.000162	2.63284E-08	0.00016226	2.63284E-08
0.215	0.000112	1.24792E-08	0.00011171	1.24792E-08
0.225	5.1E-05	2.59832E-09	5.0974E-05	2.59832E-09
0.235	9.54E-06	9.09598E-11	9.5373E-06	9.09598E-11
0.245	7.97E-06	6.34969E-11	7.9685E-06	6.34969E-11
0.255	9.89E-06	9.78366E-11	9.8912E-06	9.78366E-11
0.265	6.09E-06	3.71249E-11	6.093E-06	3.71249E-11
0.275	2.37E-06	5.60216E-12	2.3669E-06	5.60216E-12
0.285	3.51E-07	1.22902E-13	3.5057E-07	1.22902E-13
0.295	3.36E-07	1.13078E-13	3.3627E-07	1.13078E-13

F(n)	sx(f)= RAO2 x Sf PM Spectrum	sx(f)= RAO2 x Sf JONSWAP spectrum
0.005	#DIV/0!	#DIV/0!
0.015	1.5018E-125	1.5027E-125
0.025	9.03091E-16	9.03644E-16
0.035	0.000241599	0.000241747
0.045	0.030022011	0.030177681
0.055	0.06160895	0.136310199
0.065	0.04035428	0.072741074
0.075	0.016942413	0.017129073
0.085	0.001927027	0.001928216
0.095	0.00123404	0.001234795
0.105	0.000149694	0.000149786
0.115	2.09374E-08	2.09503E-08
0.125	2.43599E-05	2.43749E-05
0.135	3.49471E-05	3.49685E-05
0.145	2.37176E-05	2.37321E-05
0.155	1.01558E-05	1.0162E-05
0.165	2.70864E-06	2.7103E-06
0.175	3.32461E-07	3.32664E-07
0.185	4.00518E-11	4.00763E-11
0.195	3.74574E-08	3.74803E-08
0.205	3.60446E-08	3.60667E-08
0.215	1.34838E-08	1.3492E-08
0.225	2.23924E-09	2.24061E-09
0.235	6.31295E-11	6.31681E-11
0.245	3.58071E-11	3.5829E-11
0.255	4.51973E-11	4.52249E-11
0.265	1.41568E-11	1.41655E-11
0.275	1.77583E-12	1.77692E-12
0.285	3.25982E-14	3.26182E-14
0.295	2.52497E-14	2.52651E-14

Table 7: Data for Heave spectrum for JONSWAP and PM Spectrum

Table 8: Data for Heave response for JONSWAP and PM Spectrum

T heave	n(0,T) PM	n(0,T) JONSWAP	T heave	n(0,T) PM	n(0,T) JONSWAP
1	0.022175605	-0.000252983	31	0.002124752	-0.007352845
2	-0.009991924	-0.014569215	32	-0.001662122	-0.011223869
3	-0.005984658	0.005198936	33	0.003414576	-0.005418409
4	0.006298668	0.001226081	34	0.011772644	-0.00648883
5	-0.000599464	-0.003816534	35	0.010442633	0.00741084
6	-0.006641166	-0.007229859	36	0.004972532	0.000142723
7	-0.001637935	0.001085307	37	0.003212291	0.003402612
8	-0.000758382	0.002134803	38	-0.001280881	-0.0065636
9	-0.004351176	-0.000674708	39	-0.007653124	0.009762538
10	-0.005218934	-0.004253619	40	-0.005213419	-0.001926663
11	-0.007111562	-0.004244816	41	0.001108866	-0.001082917
12	-0.007021115	0.00277204	42	-0.000668679	-0.007944069
13	-0.000699282	-8.72501E-05	43	-0.005018373	0.008644743
14	0.000119032	-0.00332629	44	-0.002795967	-0.011055487
15	-0.006171604	0.001396305	45	0.00064058	0.000520992
16	-0.002591849	-0.022152774	46	-2.48677E-05	0.000325342
17	0.00754449	0.005065262	47	-0.000498474	-0.007662354
18	0.00466531	-0.006718335	48	0.001193014	0.005621923
19	-0.005367521	-0.009471638	49	0.001696104	-0.009275369
20	-0.00568281	-0.001334556	50	-4.01814E-05	0.002645856
21	-0.00192747	0.000688569	51	-0.001769291	0.001012356
22	-0.002402763	0.001696974	52	-0.001261805	-0.000406341
23	-0.001158489	-0.001291929	53	0.000389298	0.002619078
24	0.001236998	-4.80108E-05	54	-0.000135272	-0.000775463
25	-0.001412261	0.006706939	55	-0.000757742	-0.013062402
26	-0.003807041	-0.000218707	56	0.002756594	0.004548791
27	-0.001732581	-0.002119964	57	0.00496642	0.006212823
28	-0.00040217	-0.002190958	58	0.00065144	-0.001855022
29	0.000717477	-0.007246255	59	-0.000920045	-0.000267726
30	0.00367074	0.000529188	60	0.005541546	0.009519642

Table 8: Pitch spectrum data RAO

f(1) (Hz)	RAO	RAO^2 PM Spectrum	RAO	RAO^2 JONSWAP Spectrum
0.005	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
0.015	8.91E-06	7.94614E-11	6.09E-06	3.70746E-11
0.025	7.01E-06	4.91624E-11	3.61E-06	1.30193E-11
0.035	2.34E-05	5.48379E-10	1.45E-05	2.10697E-10
0.045	2.54E-05	6.43363E-10	2.95E-05	8.69749E-10
0.055	2.76E-05	7.6343E-10	2.78E-05	7.72952E-10
0.065	4.53E-05	2.05608E-09	8.47E-06	7.16791E-11
0.075	8.41E-06	7.0675E-11	1.03E-05	1.05371E-10
0.085	6E-05	3.59711E-09	2.02E-05	4.09683E-10
0.095	2.32E-05	5.37314E-10	4.1E-05	1.67907E-09
0.105	6.64E-05	4.40354E-09	4.67E-05	2.17647E-09
0.115	1.79E-05	3.19794E-10	7.3E-05	5.3312E-09
0.125	3.6E-05	1.29819E-09	7.31E-05	5.35057E-09
0.135	3.45E-05	1.19069E-09	6.45E-05	4.16131E-09
0.145	7.05E-05	4.96841E-09	1.83E-05	3.35505E-10
0.155	4E-05	1.59825E-09	3.12E-05	9.76532E-10
0.165	6.28E-05	3.94954E-09	6.02E-05	3.62627E-09
0.175	5.74E-05	3.30009E-09	4.24E-05	1.79784E-09
0.185	4.89E-05	2.39347E-09	5.16E-05	2.6639E-09
0.195	8.57E-06	7.3483E-11	3.4E-05	1.15878E-09
0.205	3.97E-05	1.57376E-09	3.79E-05	1.435E-09
0.215	2.42E-05	5.8718E-10	4.9E-06	2.40508E-11
0.225	2.67E-05	7.11567E-10	2.43E-05	5.9224E-10
0.235	1.83E-05	3.34295E-10	1.84E-05	3.40229E-10
0.245	1.21E-05	1.4575E-10	1.78E-06	3.18277E-12
0.255	9.91E-09	9.81248E-17	7.8E-06	6.08198E-11
0.265	5.1E-07	2.60443E-13	1.14E-06	1.30533E-12
0.275	3.14E-06	9.85512E-12	2.32E-06	5.39834E-12
0.285	4.35E-07	1.8964E-13	4.75E-09	2.25908E-17
0.295	2E-05	4.01993E-10	1.32E-05	1.74501E-10

Table 9: Pitch spectrum data RAO² x S (f)

f(1) (Hz)	S(f)PITCH (m^2s) PM Spectrum	S(f)PITCH (m^2s) JONSWAP
0.005	#DIV/0!	#DIV/0!
0.015	5.3233E-133	3.6348E-133
0.025	1.11146E-24	1.15731E-22
0.035	6.920E-13	2.374E-10
0.045	2.851E-08	5.435E-08
0.055	6.933E-11	1.667E-07
0.065	3.199E-07	2.704E-08
0.075	5.045E-09	6.359E-09
0.085	3.054E-07	3.307E-07
0.095	2.296E-07	2.352E-07
0.105	1.490E-07	1.445E-07
0.115	1.398E-08	9.250E-09
0.125	5.169E-08	8.325E-08
0.135	1.412E-09	5.271E-08
0.145	2.133E-08	1.364E-08
0.155	4.028E-09	1.228E-08
0.165	1.580E-08	1.557E-08
0.175	7.816E-11	9.940E-09
0.185	4.661E-09	9.933E-10
0.195	1.760E-09	4.081E-10
0.205	5.757E-10	2.090E-09
0.215	1.216E-09	1.141E-09
0.225	5.899E-10	4.875E-11
0.235	1.190E-10	2.263E-11
0.245	1.108E-10	3.092E-11
0.255	2.134E-11	1.240E-11
0.265	5.185E-13	1.092E-13
0.275	9.063E-13	4.684E-13
0.285	1.029E-11	6.380E-14
0.295	1.607E-11	4.529E-11

Table 10: Pitch response data RAO² x S (f)

T pitch	PM Spectrum	Jonswap Spectrum	T pitch	PM Spectrum	Jonswap Spectrum
1	-0.00024527	-0.000104751	31	-0.000809292	-0.000392203
2	-0.000232796	-0.000109702	32	0.001597921	0.001570307
3	-0.000144904	-0.000109134	33	2.39841E-05	-0.000217189
4	-4.60085E-05	0.000628908	34	-0.000175207	-7.45598E-05
5	4.50914E-05	0.000274632	35	2.82312E-05	-0.00032044
6	0.00016227	-0.000209364	36	1.33513E-06	0.000193108
7	-0.000303097	0.000207709	37	-0.000215481	-0.000169781
8	0.000167255	-4.68287E-05	38	0.00025335	-0.00040515
9	0.000390013	-0.000298565	39	-2.98957E-05	5.31133E-05
10	-0.000151565	0.000101814	40	0.000620554	-0.000186121
11	-0.000157352	-0.000400911	41	0.000270658	-0.000348654
12	8.58006E-05	-0.000729554	42	-0.000118228	7.54714E-05
13	0.000158583	-1.19331E-05	43	-0.00021421	-0.00030887
14	0.000144049	0.000155329	44	0.000105107	-0.00058538
15	0.000497038	0.000205233	45	-9.39618E-06	-0.000164189
16	-0.002161268	-0.002006273	46	-0.00011577	0.000345368
17	7.64274E-05	0.000114778	47	0.001114799	0.00060014
18	0.000245652	8.86563E-05	48	-0.000810563	-0.000958397
19	7.13914E-05	0.000229718	49	-8.78319E-05	0.000364707
20	1.3291E-05	-0.000433857	50	4.48646E-05	5.05291E-05
21	9.24765E-05	-6.50328E-05	51	-0.000112608	0.000353678
22	-0.000196117	0.000326817	52	-1.33194E-06	3.09638E-05
23	0.000161314	-0.00011645	53	0.000286996	0.000365685
24	-0.0004554	0.000130394	54	-0.000312841	0.0004082
25	-0.000380425	0.000355092	55	-2.71068E-05	-3.27821E-05
26	0.000145333	-4.9086E-05	56	-0.000628951	0.000203609
27	0.00021605	0.000411114	57	-9.33971E-05	0.000266288
28	-0.000111972	0.000712813	58	5.30657E-05	-0.000175036
29	-0.000101273	0.000108563	59	0.000166238	0.000133371
30	-1.29225E-05	-0.000235563	60	-5.80047E-05	0.000379053

Table 11: Responses of Tension leg platform due to regular waves (0.25Hz)

Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)
0	0	24	0.715	48	0.715	72	0.715
1	1.43	25	2.145	49	2.86	73	0.715
2	2.145	26	2.86	50	2.86	74	2.145
3	0	27	-0.715	51	0	75	2.86
4	-0.715	28	0	52	0.715	76	-0.715
5	2.145	29	2.86	53	2.86	77	0
6	2.86	30	2.145	54	2.86	78	2.86
7	0	31	-0.715	55	-0.715	79	2.86
8	-1.43	32	0	56	0	80	-0.715
9	1.43	33	2.86	57	2.145	81	0
10	2.86	34	2.86	58	2.86	82	2.86
11	0	35	0	59	0	83	0
12	0.715	36	0.715	60	0.715	84	0.715
13	2.86	37	2.86	61	2.145	85	2.86
14	3.575	38	1.43	62	2.86	86	1.43
15	-1.43	39	-0.715	63	0	87	2.145
16	0	40	0	64	0.715	88	0.715
17	2.86	41	2.86	65	2.86	89	2.86
18	2.86	42	2.86	66	2.86	90	-0.715
19	0	43	-0.715	67	0		
20	1.43	44	0	68	0.715		
21	2.86	45	2.86	69	2.86		
22	2.86	46	2.145	70	2.86		
23	0	47	-0.715	71	0		

Table 12: Responses of Tension leg platform due to regular waves (0.25Hz)

Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)
0	0	24	0	48	2.86	72	-2.86
1	2.86	25	5.72	49	-2.86	73	8.58
2	-1.43	26	2.86	50	7.15	74	2.86
3	5.72	27	-1.43	51	1.43	75	0
4	-1.43	28	4.29	52	-2.86	76	7.15
5	4.29	29	2.86	53	5.72	77	0
6	5.72	30	-2.86	54	1.43	78	2.86
7	0	31	4.29	55	-2.86	79	7.15
8	2.145	32	2.86	56	7.15	80	-2.86
9	2.86	33	0	57	2.86	81	5.72

10	-0.715	34	5.72	58	-2.86	82	4.29
11	5.72	35	2.86	59	5.72	83	-2.86
12	4.29	36	0	60	0	84	5.72
13	-1.43	37	5.72	61	2.86	85	4.29
14	5.72	38	1.43	62	5.72	86	-2.86
15	2.86	39	-1.43	63	-2.86	87	4.29
16	1.43	40	5.72	64	2.86	88	-2.86
17	5.72	41	0	65	5.72	89	5.72
18	2.86	42	2.86	66	-4.29	90	2.86
19	0	43	5.72	67	5.72		
20	5.72	44	0	68	4.29		
21	0	45	5.72	69	-4.29		
22	2.86	46	2.86	70	7.15		
23	5.72	47	5.72	71	2.86		

Table 13: Responses of Tension leg platform due to regular waves (0.25Hz)

Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)
0	0	24	-6	48	-8	72	-2
1	2	25	5	49	7	73	-8
2	-2	26	-8	50	1	74	6
3	4	27	6	51	-2	75	-4
4	2	28	-3	52	4	76	7
5	-2	29	4	53	-2	77	0
6	-8	30	-5	54	6	78	-7
7	6	31	3	55	-6	79	4
8	-6	32	4	56	6	80	-2
9	7	33	-2	57	-7	81	1
10	2	34	2	58	4	82	-7
11	-4	35	-6	59	-4	83	1
12	2	36	7	60	2	84	7
13	-1	37	-7	61	-2	85	-7
14	2	38	6	62	4	86	7
15	8	39	-6	63	-6	87	-5
16	6	40	4	64	-2	88	7
17	-4	41	-2	65	7	89	0
18	4	42	5	66	-8	90	6
19	-6	43	-2	67	6		
20	4	44	-7	68	-4		

21	-6	45	-2	69	1		
22	2	46	3	70	-4		
23	6	47	7.6	71	6		

Table 14: Responses of Tension leg platform due to regular waves (0.25Hz)

Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)	Time (sec)	Response (cm)
0	0	24	7	48	-8	72	-9
1	-6	25	2	49	8	73	6
2	7	26	-6	50	-7	74	-4
3	-6	27	7	51	7	75	5
4	5	28	-8	52	-7	76	-4
5	-7	29	5	53	8	77	-9
6	7	30	-2	54	-7	78	-2
7	-6	31	2	55	3	79	6
8	-6	32	-4	56	-6	80	-6
9	7	33	8	57	4	81	0
10	-7	34	-8	58	9	82	7
11	-4	35	-5	59	-5	83	-4
12	3	36	8	60	4	84	3
13	8	37	-8	61	-7	85	-6
14	0	38	5	62	2	86	7
15	-3	39	-6	63	-5	87	0
16	-8	40	5	64	4	88	-5
17	6	41	-8	65	-4	89	-9
18	-4	42	-1	66	8	90	1
19	-8	43	2	67	-4		
20	2	44	8	68	6		
21	-6	45	-7	69	-2		
22	3	46	3	70	-9		
23	-7	47	8	71	-4		

No.	Description	Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Dates	21-Jul	28-Jul	4-Aug	11-Aug	18-Aug	25-Aug	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct
1	**FYP Project Selection**																
	Approaching Supervisor		■														
	Discuss/ propose title			■													
2	**Preliminary Research**																
	Start of research				■	■	■										
	Develope literature review				■	■	■	■	■	■	■	■		■	■	■	
	Submission of Preliminary Report							☑									
3	**Seminar**							■	■								
4	**Project research continuation**																
	Study of Wave spectrum - P-M and JONSWAP spectrum								■	■	■	■					
	Fabrication of model														■	■	■
	Submission of Progress Report							☑									
	Submission of Interim Report - final draft													☑			
	Oral presentation																☑

■ Process
☑ Delivarables
Mid-semester break

Table 15: Project Schedule for Final Year Project 1.

Final Year Project VAB 4043
SEMESTER Jan 2009

No.	Description	Weeks	1	2	3	4	5	6	7	8	9		10	11	12	13	14	15
		Dates	18-Jan	25-Jan	3-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May
1	**Project Research (continuation)**																	
	Heave Motion Analysis																	
	Pitch Motion Analysis																	
	Analysis of ITTC Spectrum																	
	Wave spectrum affect on motion																	
	Preparatrion for progress report							☑										
	Preparation for poster presentation												☑					
	Preparation for Disertation report														☑			
	Preparation for Oral Presentation																	☑
2	**Project laboratory Experiment**																	
	Laboratory check-up																	
	Model Setting																	
	Experiment Trial run																	
	Experiment testing																	
	Data interpretation																	
	Model Analysis																	

Completed
Process
☑ Delivarables
Mid-semester break